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ENVIRONMENTAL BURN-IN EFFECTIVENESS

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FOR THE COMMANDER

AMBROSE B. NUTT
Director
Vehicle Equipment Division

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This report considers the effectiveness of current industry practice in the burn-in of avionics equipment. The burn-in test results for six avionics systems are analyzed using the chance Defective Exponential model for the failure rate. Based on the mode, effectiveness measures for burn-in are developed. Flight test results are also evaluated to determine the adequacy of current burn-in techniques. Cost effectiveness considerations for the burn-in process are addressed. Results of an industry survey on current

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ABSTRACT, cont'd.

practice and opinions concerning various issues in the burn-in of avionics are presented.

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FOREWORD

This report was prepared under Contract No. F33615-79-C-3411 for the Flight Dynamics Laboratory, Wright-Patterson AFB, Dayton, Ohio. This work was performed under Project No. 2402 and Task No. 240204. Mr. David L. Earls of the Environmental Control Branch (FIE) was the project manager and provided valuable guidance throughout the program. Dr. Alan H. Burkhard, also from AFWAL/FIE, and Mr. Joseph R. Korosi, from the Aeronautical Systems Division, provided valuable guidance during the initial program design and during the program reviews.

MCAIR is indebted to the numerous companies who responded to the industry survey. Their time and effort provided a detailed view of industry practice and valuable suggestions for the improvement of burn-in.

MCAIR also thanks the equipment suppliers who provided data and suggestions for the detailed analysis of the selected equipments: Messrs. Virgil Norquist, Dave Behan, and Alex Bezat of Honeywell Avionics Division, Mr. John Jeffries of General Electric Aircraft Equipment Division, Mr. John Littlefield of Litton Guidance and Control Systems Division, Mr. John Bowers of McDonnell-Douglas Electronics Company, Mr. Charles Wierzbicki of Bendix Flight Systems, and Mr. Zen Milunas of Litton Aero Products.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AFCS	Automatic Flight Control Set
AFFDL	Air Force Flight Dynamics Laboratory, Dayton, Ohio
AT	Acceptance Test
ATP	Acceptance Test Procedure
C_B	Cost if burn-in is performed
CDE	Chance-Defective-Exponential
CDF	Cumulative Distribution Function
C_{FR}	Cost of a field repair
C_{NB}	Cost if no burn-in is performed
CND	Could-Not-Duplicate
CRT	Cathode Ray Tube
C_T	EBI test cost for M units
C_T^*	Value of perfect burn-in test
DA	Double Amplitude
DADC	Digital Air Data Computer
DFD	Delivered Fraction Defective
DU	Display Unit
EBI	Environmental Burn-in
EC	Engaging Controller
FGS	Flight Guidance Set
$F(T)$	$Pr\ (t < T)$
$\bar{F}(T)$	$1 - F(T)$
$f(t)$	$\frac{d}{dt}F(t)$
FTFD	Flight Test Fraction Defective
HUD	Head-up Display Set

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS (Continued)

IC	Integrated Circuit
iid	Independent and identically distributed
IMU	Inertial Measurement Unit
INS	Inertial Navigation Set
INU	Inertial Navigation Unit
K	Number of cycles in burn-in
LRU	Line Replaceable Unit
M	Number of units
McAIR	McDonnell Aircraft Company
MFHBF	Mean Flight Hours Between Failure
MIC	Microcircuit
m_j	Number of failures in cycle j
M_j	Number of units which attempt cycle j and have passed cycles 1, 2, ..., (J-1) without failure
NCI	Navigation Control Indicator
N_p	Number of parts in a unit (thousands)
PC	Pitch Computer
PCB	Printed Circuit Board
PFD	Produced Fraction Defective
Pr(∘)	Probability ∘ is true
P_r	Probability a unit fails initial ground test
PWB	Printed Wiring Board
r_j	Discrete Failure Rate
$\hat{r}_j$	Estimate of discrete failure rate
RYC	Roll/Yaw Computer
SDP	Signal Data Processor
SF	Survival Function

SFD	Surviving Fraction Defective
SFS	Stick Force Sensor
SIF	Screen Improvement Factor
TFD	Total Fraction Defective
WORK	Workmanship
XISTOR	Transistor
Δt	Length of cycle in equipment on-hours
$\lambda(t)$	Continuous failure rate = $\frac{F(t)}{\bar{F}(t)}$
$\hat{\bar{\lambda}}$	Average failure rate
$\hat{\mu}_o$	Estimate of MFHBF
α	Probability of rejecting a hypothesis if it is true
$\chi^2_{(x)(y)}$	Value of Chi-Square random variable with x degrees of freedom and $Pr(z < \chi^2_{(x)(y)}) = y$
$\forall$	For all

SECTION I

INTRODUCTION AND SUMMARY

Among avionics suppliers, temperature cycling is often used as an environmental test to precipitate equipment defects. Various suppliers may also use some form of vibration environment (sine, random) in addition to the temperature cycle. The process is often referred to by various names: debugging, burn-in, environmental screening or removal of infant mortality. This test process will be referred to as Environmental Burn-in (EBI).

The object of this study was to assess the technical merit of the EBI test process. This involved two related tasks. First, a survey of the avionics industry to determine the current practices in EBI for both military and commercial avionics and to assess their effectiveness, the factors influencing the screen design, and suggested improvements in the EBI test process.

The second task required the detailed evaluation of the EBI effectiveness on avionics systems representative of current production hardware and EBI test design. This involved first the value of burn-in as a vehicle for reliability improvement and second the length of the process: should it be longer and more thorough or should it be curtailed, in the interest of economy and possible wear out? Other issues investigated were the failure rate of units after first failure and repair, the compatibility of the performance test in burn-in with subsequent acceptance tests, and the cost effectiveness of the burn-in process. In addition, the failure rate in the aircraft use environment was examined to determine if the existing burn-in was sufficient to eliminate infant mortality.

Failure rate statistics from six avionics systems were used in this study: the Head-Up Display Set, Inertial Navigation Set, and Automatic Flight Control Set from military aircraft and the Flight Guidance Set, Inertial Navigation Unit, and Digital Air Data Computer from commercial aircraft. The failure rates for the various populations of units in the EBI were analyzed separately; e.g., 1) The population of units prior to EBI, 2) The population of units which have had one failure in EBI, and 3) The population which has had two failures, etc. The failure rate for each of these populations was estimated by statistical methods. This approach is superior to methods which do not consider the time order of failure because it yields: 1) an unbiased estimate of the population failure rate, 2) a determination of the requirements for retest after failure, and 3) an estimate of the fraction defective prior to EBI.

An evaluation of the EBI thoroughness was provided by observing the behavior of the ensemble equipment reliability when initially subjected to the actual aircraft flight environment.

Results from production flight operations at MCAIR were used for this purpose.

Salient results are given in Sections II, IV and V and in the Conclusions, Section VII.

In brief, the detailed statistical analysis of the six systems demonstrated that burn-in improves the ensemble reliability and no "wearout" degradation is apparent, but that the number of cycles used on military systems can be reduced up to two-thirds, offering considerable savings in time and cost.

On the other hand, more extensive burn-in may be desirable on failed units after repair. Also the content of burn-in tests should be examined to make them more compatible with acceptance tests, and to make both of them compatible with the real-world operational environment.

The industry survey indicated that MIL-STD-781B is the "unofficial" industry standard for EBI. The EBI for commercial use is similar to that used for military hardware although generally less severe. Suggested BI improvements include: using a failure free criterion, improving the EBI performance test and adding a separate random vibration test.

In the course of the study, the Chance-Defective Exponential model was used and effectiveness measures developed. The model was used not only on the EBI tests, but on the results of predelivery flight tests. It may also be useful in other analyses. A complete description is given in Appendix A.

Recommendations are provided concerning the improvement of the EBI process along with suggestions for further research on environmental stress screening.

SECTION II

INDUSTRY SURVEY RESULTS

A survey was conducted of avionic equipment manufacturers to determine current industry practice in the conduct of environmental screening and to gather opinions on issues concerning the screening process. The survey, reproduced as Appendix B, was distributed to 114 potential respondents. Thirty-three organizations, or 29%, returned answers, as shown in Table 1. In some cases more than one questionnaire was returned from a company, representing various projects within the organization. These are indicated by (*).

1. ENVIRONMENTAL SCREEN CHARACTERISTICS - In the survey, the respondents were asked to describe an environmental screen for an avionic LRU which is representative of their operation. The responses are summarized below by screen design characteristics (i.e. number of cycles, temperature limits, vibration parameters, etc.).

The primary environmental screen used is a thermal cycle. The distribution of the hot and cold temperature limits used in the cycle are shown in Figures 1 and 2 respectively. As evidenced in the figures, a high temperature limit of 55°C or 71°C is most common for both military and commercial users. One space application required a high temperature of 125°C. In the low temperature limit -55°C is most commonly used for military equipment. For the commercial systems the low temperature limit tends to be greater than -55°C. It is not surprising that the most common high (55°C, 71°C) and low (-55°C) temperature limits are also the test limits specified in MIL-STD-781B for test levels E and F.

A histogram of the cycle lengths is shown in Figure 3. Cycle lengths of six and eight hours are most common. These times provide a convenient number of cycles per 24 hour day. The number of thermal cycles used varies from one, for a space system, to 70, for a military equipment. Figure 4 is a histogram of the number of cycles used. As evidenced by the figure, the number of cycles used varies quite widely, with values of four and ten being the most common. The military equipments tend to use a larger number of cycles. However, one commercial system uses 21 cycles. The number of failure free cycles required is shown in Figure 5. The most common requirement is the last cycle being failure free. The military systems use more failure free cycles than the commercial units.

The temperature rate of change used for the heating and cooling portion of the cycle was generally between 3-5°C/min. One respondent reported using 25°C/min.

TABLE 1. SURVEY RESPONDENTS

Motorola Incorporated, Government Electronics Division
Rockwell International, Avionics and Missiles Group
Rockwell International, North American Aircraft Division
SCI Systems, Incorporated
AIL Division, Eaton Corporation
Lockheed California Company
Grumman Aerospace Corporation
Norden Systems, Division of UTC
Singer-Kearfott Division
Sperry Flight Systems
Goodyear Aerospace Corporation*
Rockwell International, Autonetics Strategic Systems Division
Sanders Associates, Incorporated
Rockwell International, Collins Communications Systems Division
Ford Aerospace and Communications Corporation, Aeronutronic Division
Bell Helicopter - Textron
Tracor Incorporated, Aerospace Group*
Hughes Aircraft Company, Radar Systems Group*
Litton Aero Products
Litton Guidance and Control Systems Division
Honeywell Incorporated, Avionics Division
IBM, Federal Systems Division
Hamilton Standard, Division of UTC
Watkins-Johnson Company*
Northrop Corporation, Aircraft Division
Vought Corporation*
Boeing Company*
Martin Marietta Aerospace, Orlando Division*
Arinc Research Corporation*
General Electric, Aircraft Equipment Division
Litton Systems Incorporated, Data Systems Division
General Dynamics, Fort Worth Division
Bendix, Flight Systems Division

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*Multiple responses.

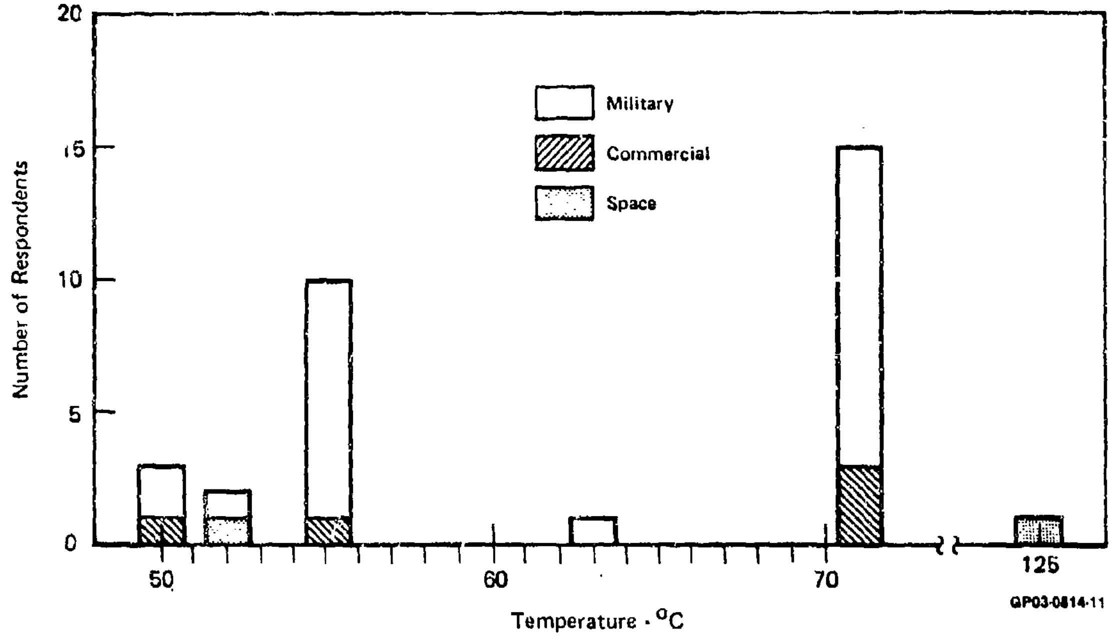

Figure 1. Thermal Cycle High Temperature Limits

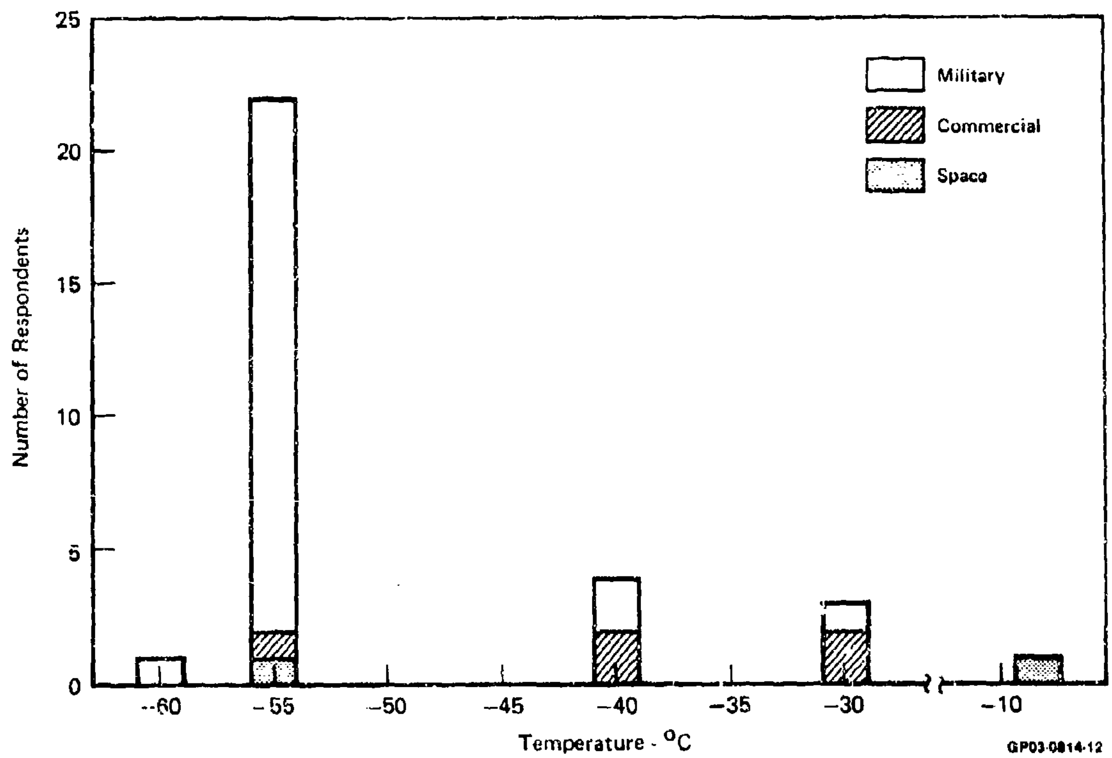

Figure 2. Thermal Cycle Low Temperature Limits

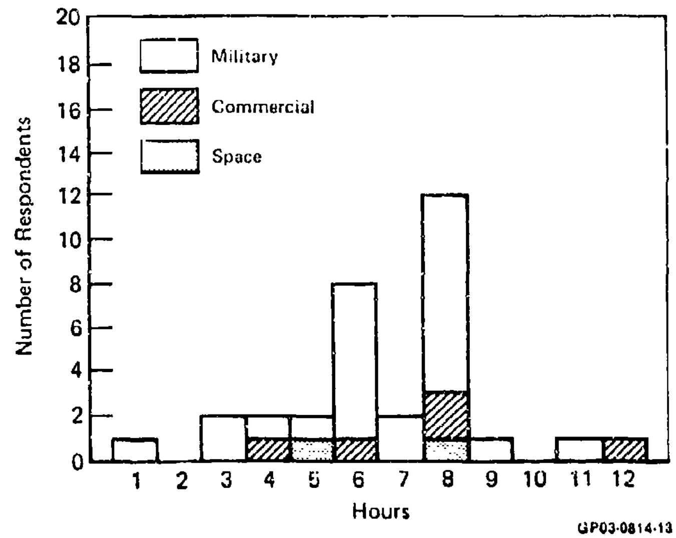

Figure 3. Cycle Length

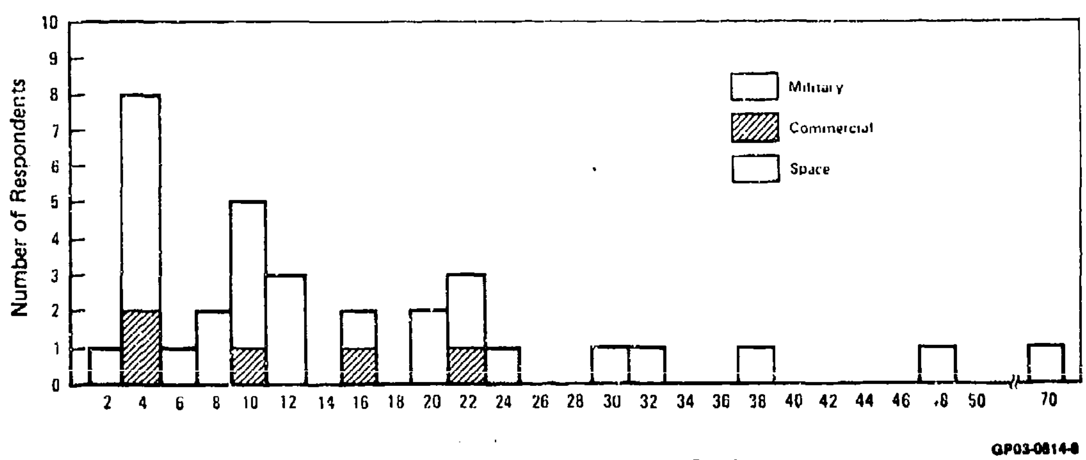

Figure 4. Number of Thermal Cycles

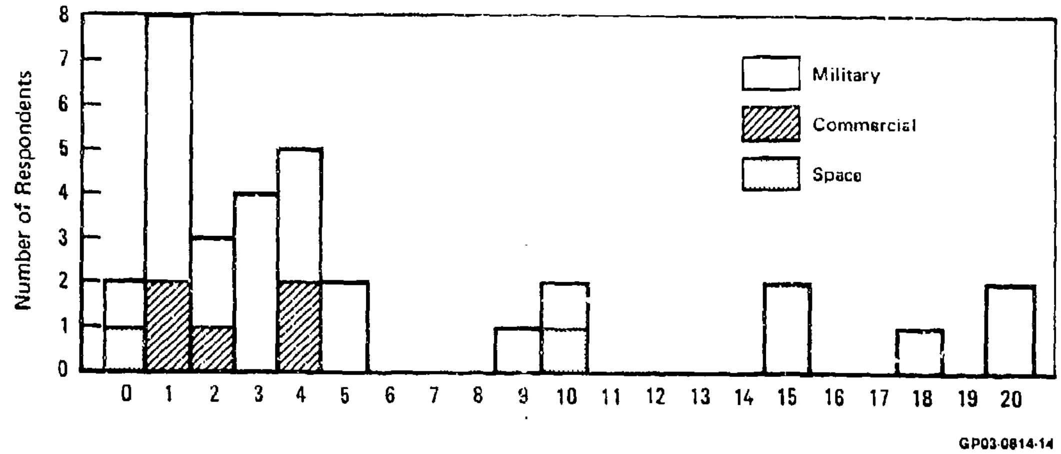

Figure 5. Number of Failure Free Cycles

The use of a vibration environment during the temperature cycle was reported by 67% (21/31) of the respondents. In all cases the vibration environment was sinusoidal and the duration and levels consistent with the requirements of MIL-STD-781B (2.2 gpk @ 20-60Hz, 10 min. each on-hour). No random vibration was used during the temperature cycle. However, nine of the respondents indicated that a random vibration test was used as a separate environmental screen at the LRU level.

The vibration levels ranged from 3 to 6.2 gRMS. The average value was 5.5 gRMS. All users of random vibration required testing in at least 2 axes with two thirds of the tests specifying vibration in all three axes. The duration was evenly divided between 5 and 10 minutes per axis.

The location of the random vibration test in the production process varied among the respondents. One used the test prior to temperature cycling, two used it after the temperature cycle, two used it before and after and three conducted it between two temperature cycles. All respondents indicated the test had to be completed failure free.

Figure 6 shows the different vibration spectra used for the random vibration test. The number of respondents using each of the spectra were 1, 3 and 2 for Figures a, b and c respectively. All random vibration use was reported on military and space equipment. No use of random vibration was reported on commercial equipment.

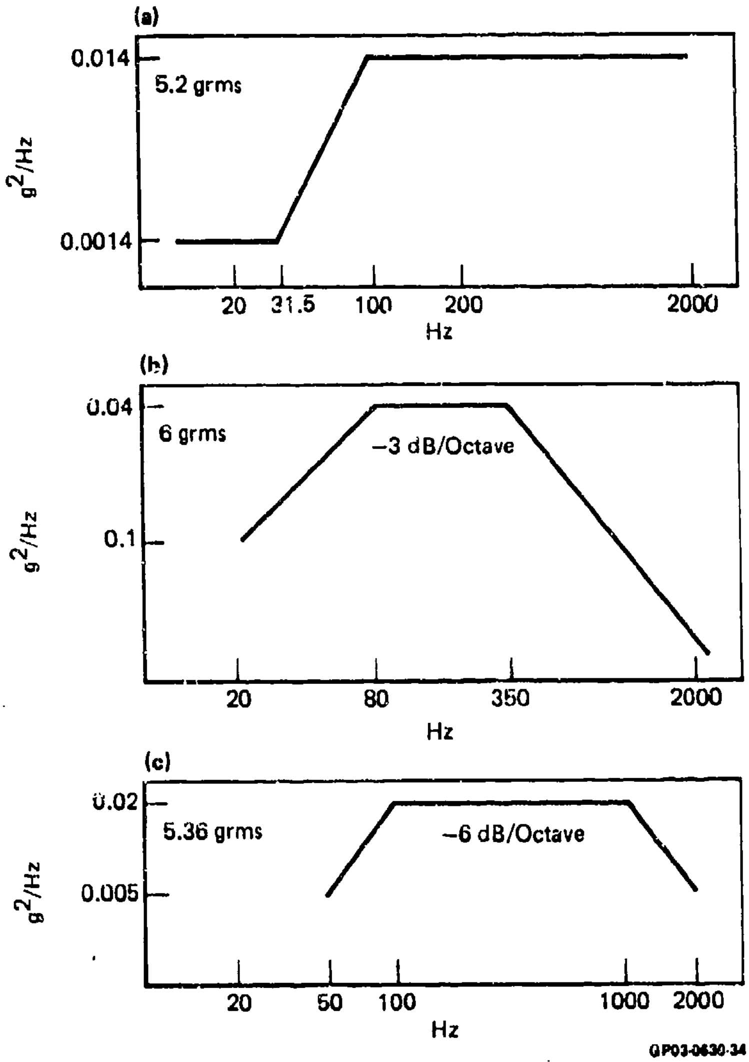

Figure 6. Environmental Screen Random Vibration Spectra

2. BURN-IN DEFECT TYPES - The survey requested an estimate of the percentage of failures by defect type for the equipment in the temperature cycle burn-in. The results are summarized in Table 2. As shown in the table, the dominant failure cause is parts, followed by workmanship defects. The percentages of operator errors, design defects and could-not-duplicates average about the same values.

Table 2 shows a high variance in the percentage for the various defect types. This may be attributed to the difference in production maturity of the hardware represented in the sample. In early production the design and work/process type defects are significant and become negligible as the production process matures. For mature equipment, parts defects become the dominant defect type as shown in Section IV in the detailed analysis of selected equipments.

Respondents were also asked to indicate the primary source of failure for the various causes. For part failures, the most common source was defective IC's and semiconductors (Diodes and Transistors). Problems cited include: temperature sensitivity, substrate problems, weld bonds, and particle contamination. Capacitors and transformers were also listed as a significant source.

TABLE 2. BURN-IN FAILURE DISTRIBUTION IN PERCENT

Defect Type	Range (%)	Mean (%)	Median (%)
Part	5 - 97	46	40
Work/Process	3 - 55	30	25
Design	0 - 75	8	0
Test Equipment/ Operator Error	0 - 40	7	5
CND	0 - 45	8	4

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In the area of workmanship, soldering defects were the most common source of problems. Also listed were incorrect assembly, wrong parts, rough handling, broken parts, open PCB etches and improper wiring. Only two design problems were listed: transformer insulation and IC temperature compensation.

3. <u>INDUSTRY ENVIRONMENTAL SCREENING EXPERIENCE</u> - The survey requested an indication of what environments had been used as screens and whether they were found to be effective. Table 3 shows the percentage of respondents that had some experience with the listed environments as a defect screen. All respondents (32) indicated they had used a temperature cycle of some form. The second column of the table indicates the percentage of those with

experience who also found the environment to be an effective screen. The responses are also broken down by the respondee avionic product type: Military only (MIL), Commercial only (COM), and both military and commercial (MIL & COM). In general, the respondents indicated that temperature cycling tests and random vibration tests were the most effective of those listed. As shown in the table, there seems to be very little experience with combined temperature cycling and random vibration tests. However, all users feel the test is effective. Other environments which were listed as effective by only one respondent were: power cycling at high temperature, sine vibration at fixed frequency, and temperature cycling with sine sweep vibration.

TABLE 3. EXPERIENCE WITH ENVIRONMENTAL SCREENS

Environment	Experience (Percent)				Effective (Percent)			
	Total	MIL	Com	MIL/Com	Total	MIL	Com	MIL/Com
Temperature Cycle with Sine Vibration	78	78	50	83	96	100	100	90
Temperature Cycle with Random Vibration	16	22	0	8	100	100	–	100
Temperature Cycle without Vibration	63	56	100	67	90	90	100	88
Sine Sweep Vibration	34	33	50	33	55	67	0	50
Random Vibration	53	44	50	67	100	100	100	100
Shock	19	17	50	17	50	67	100	0
High Humidity	9	6	50	8	67	100	100	0
High Altitude	6	6	0	8	50	100	–	0

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Number of Responses:

MIL:	18
Com:	2
MIL/Com:	12
Total	32

4. <u>INDUSTRY OPINIONS</u> - The survey requested opinions concerning various issues relating to the design and effectiveness of the environmental screening process. The results of this EBI opinion poll are presented in this section.

Q. Many temperature cycling screens consist of a soak at high temperature of 2 or more hours. It has been suggested that the soak is of little value and should be deleted in favor of additional cycling. Do you:

	MIL	COM	MIL & COM	TOTAL
Agree	14	4	8	26
Disagree	9	1	7	17
No Opinion	3	0	0	3

Q. The low level sine vibration used in many temperature cycling screens is of little value in detecting quality defects.

	MIL	COM	MIL & COM	TOTAL
Agree	18	3	9	30
Disagree	6	1	6	13
No Opinion	2	1	0	3

Q. Please rank the following vibration techniques in order of their general effectiveness in detecting production defects. 1 = HIGHEST.

		Sine	Sine Sweep	Random
	1	0	3	46
Rank	2	4	42	0
	3	43	2	1

In the above question respondents were also asked to indicate what source of information was used to provide the ranking. Results were:

Personal Experience	28%
Literature (Papers, reports, etc.)	21%
Company Experience	26%
Engineering Judgment	25%

Q. Do you feel that the effectiveness of environmental screens, in detecting production defects, would be improved if the screen environment were representative of actual service flight conditions (e.g. vibration levels and spectra, temperature profile, etc.)?

	MIL	COM	MIL & COM	TOTAL
Yes	9	1	6	16
No	14	4	9	27
No Opinion	3	0	0	3

Q. Do you feel that a combined temperature and vibration screen is more effective in detecting production defects than the use of both these environments separately?

	MIL	COM	MIL & COM	TOTAL
Yes	14	2	8	24
No	6	3	6	15
No Opinion	6	0	1	7

5. MILITARY VS. COMMERCIAL SCREENING PRACTICES - Some of the manufacturers surveyed produce both military and commercial avionics of comparable function. These suppliers were asked to indicate what differences, if any, existed between the types of environmental screens used. Of the thirteen respondents who produce both military and commercial avionics, nine indicated that different screening tests were used: one used no screens on commercial equipment; two indicated a high-temperature-only burn-in for commercial use, a temperature cycle for military; three indicated that the temperature cycle was similar but the commercial used no vibration; and three indicated the number of cycles used was less for commercial. Two suppliers indicated that differences had existed in the past, but that burn-in for new commercial equipment was similar to that used for military programs.

Four reasons were cited as the primary causes for the differing screening requirements. They were (in order of decreasing frequency): customer requirements, use environment, cost and reliability requirements.

6. ENVIRONMENTAL BURN-IN DESIGN - In the survey respondents were asked to indicate the factors which primarily influence the design of a screen for a new production item. The factors are listed below in decreasing order of preference. The percent of the respondents for an item is shown by supplier product type.

	MIL	COM	MIL/COM	TOTAL
1. Previous experience on similar equipment	100	50	83	91
2. Customers desires	53	50	92	67
3. Equipment Characteristics	58	50	83	67
4. Equipment reliability requirements	58	0	83	64
5. Use environment	53	0	75	58
6. Existing environmental facilities	37	0	75	48
7. Test operating cost	26	0	58	36
Number of Responses	19	2	12	33

The number of cycles used was determined by either previous experience or the equipment reliability requirements. The respondents indicated that the number of cycles used was proportional to the stringency of the reliability requirement. This was especially important if a reliability demonstration test was required.

The burn-in environment was determined by three factors: existing test facilities, use environment, and the qualification test environment. Many respondents indicated that the customer requirements dictated the screen design and their effort was to develop the most cost effective screen within these constraints. One respondent indicated that the use of random vibration was influenced by the customer's requirements.

7. CHANGING EQUIPMENT ENVIRONMENTAL SCREENS - The survey asked if the environmental screen that they considered typical had been changed since the start of production, and if so what motivated the change. Of 37 respondents, 16 or 41% indicated that the screen had changed. Five types of changes were listed as shown in Table 4. The number of respondents is shown in parenthesis.

TABLE 4. ENVIRONMENTAL SCREEN CHANGES

Change	Reason
Increased Number of Cycles (8)	• Improve Reliability (2) • Program Requirement (2) • Low Field MTBF (2) • Stabilize Equipment Design (1) • Reduce Infant Mortality (1)
Added Random Vibration (3)	• Needed More Effective Screen (2) • Low Field MTBF (1)
Decreased Number of Cycles (3)	• Low Failure Rate (2) • Cost Effective (1)
Added Burn-In (1)	• Low Field MTBF (1)
Increased Vibration Level (1)	• Low Field MTBF (1)

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As shown above, changes to the initial EBI test design result primarily from the analysis of two areas. The EBI failure rate is used to determine if the test length (number of cycles) can be decreased. Field MTBF is used to indicate if an improved EBI test is required. When such is the case, the EBI improvement is either to increase the number of burn-in cycles or add a random vibration test. Thus it would appear that the primary measures of screen sufficiency are the burn-in failure rate and the field MTBF.

8. INDUSTRY COMMENTS - The last question on the survey asked respondents to give their comments on where the greatest potential lies for improving the effectiveness of environmental screening techniques. Any additional comments were also solicited. The product type of the respondents company is shown in parenthesis after the comment.

a. Random Vibration and Combined Environments Testing

(1) MIL-STD-781C combined environments, reliability testing has gone beyond reason, forcing related environmental screening and reliability testing to become extremely expensive. A random vibration "Workmanship Screen" followed by a "Temperature cycling screen" is favored. These separate screens are manageable from both a production schedule and production cost standpoint. Combined environments testing requires too expensive and too much space-occupying facilities. (MIL)

(2) Perform vibration prior to temperature cycling rather than performing the tests simultaneously. This would greatly reduce capital investment costs and would be just as effective. The reduced cost would make it easier to cost justify temperature cycling. (MIL)

(3) The greatest potential for improvement is to find a reasonable combination of temperature cycling and random vibration. Rapid implementation depends upon showing that vibration and temperature cycling need not be conducted concurrently in the same chamber. (MIL/COM)

(4) To be effective, screens must accelerate the occurrence of failures which would otherwise take place in the field. This must be done without introducing additional types of failures which would not occur in the equipment use environment. Rapid thermal changes coupled with periodic random vibration and equipment power cycling, offer the most promise. The development of an inexpensive way to simulate random vibration would be a major step toward making this type of screening available in a cost effective manner. (MIL/COM)

(5) Random vibration used prior to the thermal cycling phase is considered especially effective for uncovering quality problems. (MIL/COM)

(6) Further study of random vibration should be made to determine such factors as safe and effective magnitudes and durations. (MIL)

(7) The real environment, i.e., that the equipment will be exposed to, must be known. "F-15 environment" is not good enough. Actual measurements regarding vibration levels and temperature/humidity rate of change must be provided to the contractor to achieve a proper design initially and a proper test program prior to delivery. (MIL)

(8) Alignment of screening technique to simulate aircraft environment, including real time vibration and fast temperature/altitude excursions for accelerated ascent/descent. (MIL)

b. Failure Free Requirements

(1) Burn-in portion of test should be more severe (i.e. higher temperature, longer cycles, more cycles) than failure free portion if the objective is basically to eliminate marginal components and infant mortality. The failure free portion should be used only as confirmation of system integrity after burn-in. Since infant failures are still possible, even after burn-in, the failure free portion of the test should not be used as a measurement of mature system reliability unless field failures later confirm the data accumulated during the production testing. Eliminating the threat of penalties if failures occur would reduce the cost and encourage wider acceptance of this type of test program. (MIL)

(2) Experience indicates that the use of failure free burn-in is an exceptional tool. Any failure in the final acceptance test requires restart of the failure free period. All failures must be included for the burn-in to be effective, including test equipment induced. Recommended period is 50 hours. (MIL/COM)

(3) Believe military customers should specify only an end item failure free period in a temperature/vibration environment and let contractors select most efficient screens to assure success in the failure free period. (MIL)

(4) Another area that needs investigation is the length of failure free operation that is required. Long failure free requirements add delivery uncertainty and risk dollars. It appears that burn-in length can be more cost effectively specified by minimum length rather than by failure free criteria. (MIL/COM)

c. <u>Burn-In Analysis</u>

(1) Believe screens should be adaptive. More screening makes sense during initial production; less screening is needed for a mature product. (MIL)

(2) An effective screen should be based on analysis of previous test experience, equated to hardware performance in the field. Too often, no attempt is made to evaluate tests against Operational Performance Data. Thus the efficiency of the test as an eliminator of infant mortality failures is never known. (MIL/COM)

(3) Finding a way to provide a control so that the real effectiveness of the screen can be measured within the cost and time constraints of a normal program. (MIL/COM)

d. <u>More Cycling</u>

(1) Concentrate on more temperature cycles (or temp shock) rather than dwelling at any particular temperature. (MIL)

(2) Decrease the dwell time at temperature extremes and increase number of cycles. (MIL)

(3) The greatest potential lies in accelerating test time by increasing the frequency of cycling and reducing the duration of each cycle to the minimum required for temperature stabilization. (MIL)

e. <u>Equipment Testing in Burn-in</u>

(1) The use of environmental screening serves to stimulate the occurrence of a failure. Experience shows that the high percentage of first time occurrences are intermittent. Therefore, the detectability of that intermittent occurrence is of extreme importance. Thus, the greatest potential lies in improving the test efficiency by improving the detection monitoring frequency. This may require creative solutions in electrical design of certain types of equipments. (MIL/COM)

(2) The greatest potential lies in the adequacy of the test to detect intermittent failure conditions. Also, the ability to isolate the cause and repair at the lower assembly. (MIL)

(3) The best method of improving environmental screens effectiveness is by constant monitoring of all performance parameters during the screens to detect and correct intermittent conditions. (MIL/COM)

f. Potpourri

(1) The environmental screen should influence the initial equipment design in the following areas: (a) the equipment should be designed so that it can be subjected to a vibration screen hard-mounted without vibration isolators. Presently on some designs, the isolators are an integral part of the equipment; (b) On blower cooled equipment, consider the addition of a test connector to allow the internal blower to be operated while the unit power is turned off, thereby allowing a much greater rate of temperature change during the transition from hot to cold. (MIL)

(2) The military must issue a specific specification on "black-box" environmental screening. The variance in requirements from program to program and the dispersion in knowledge of the subject continues to lead to non-optimum equipment selections and equipment reliability. (MIL/COM)

(3) Better government contract definition of real requirements - suppliers usually wind up vastly overtesting (expensive) due to "shopping list" requirements. (MIL/COM)

(4) Biggest improvement potential probably at card/ component levels. (MIL)

9. ASSESSMENT OF SURVEY RESULTS AND FUTURE DEVELOPMENTS - The results of the survey were reviewed to determine general industry practice in the conduct of EBI and draw interferences as to the future evolution of the test process. With respect to the first of these, it is clear from the foregoing that MIL-STD-781B has had a major influence in the design of the environmental aspects of EBI. That this should be the case is not surprising. Many contracts for military hardware have required a reliability demonstration test and/or a reliability production sample test to be performed using MIL-STD-781B (test levels E and F). This standard, in addition to specifying the test environment and decision statistics, requires that any burn-in performed on the test sample must also be applied to all production units. This requirement, coupled with the requirement to pass the reliability test, make the 781B test environment a natural choice for burn-in. The availability of existing test facilities which satisfy the environmental requirements of 781B reinforce this choice.

There appears to be a moderate level of industry experience (53%) with the use of random vibration as a screen for workmanship defects. It was indicated to be an effective screen by all with experience in its use and was selected as the most effective vibration technique by almost all respondents. One respondent with experience in avionics for helicopters indicated that sine-sweep was the most effective vibration technique.

The EBI tests used for commercial avionics are generally less severe (temperature limits, use of vibration and number of cycles) than those used for military products. However, there is some indication they are evolving toward the military levels. Whether this is because of the effectiveness of the 781B tests or a result of the economies gained from the use of common facilities and test procedures is not clear.

As evidenced by Figures 4 and 5, the EBI test length and the failure-free criteria varies quite widely in general use. Attempts to explain this variation using the equipment part count were not successful, indicating no general industry practice in this regard. These parameters (test length and failure-free criteria) are specified primarily based on past experience and the customer's desires. There is also a general tendency to make the test length proportional to the reliability requirement (i.e. the higher the reliability the more cycles required). Unlike the EBI test environment, no cohesive industry accepted practice is used to establish test length and failure-free requirements. In most cases it appears that the test duration and discipline (fail-free) remain unchanged from the initial design unless significant field use problems are encountered. This would indicate a general lack of flexibility in tailoring the EBI to production results and an industry belief that increasing the length of EBI improves the end item reliability. As shown in Section IV, the link between increased test length and improved reliability rapidly approaches diminishing returns when a consecutive failure-free requirement is used. The lack of flexibility is probably a reflection of the degree of difficulty in changing supplier/prime contractor/ Government related contract provisions and the reluctance of human nature to change horses in the middle-of-the-stream.

Future development of the EBI test environment for military systems can be viewed as near term (3-5 years) and long term (5-10 years). In the near term the current philosophy of developing tests based on the efficient stimulation of defects will continue. New tests added to the basic 781B temperature cycle will be chosen based on their ability to stimulate hardware defects in a short time as opposed to the simulation of the actual service experience. In this regard the use of high level random vibration test as a separate adjunct to the basic temperature cycle is the industry candidate for improving EBI. The current debate is concerned with where to place the test (before, between or after

temperature cycling) and what vibration levels and spectrum should be used. The survey indicated that before or between temperature cycling are the prefered locations. The random vibration screen in most common use is the test described in NAVMAT P-9492, the Navy Manufacturing Screening Program (6 grms for 5-10 min/axis with the spectrum of Figure 6b). Whether this test or any of the high level (4-6 grms) random vibration tests are effective in terms of ensemble reliability improvement and significantly superior to other vibration methods or merely derigueur in the design of new EBI schemes is unknown. A comprehensive evaluation of the effectiveness of vibration as a screen for defective equipment would provide needed guidance in this area.

In the far term the development of EBI is less clear. There appears to be a philosophical conflict developing with regard to the fundamental design approach for the EBI environment. In the next five years the stimulation approach as exemplified by NAVMAT P-9492 will receive considerable attention and increased use on new programs. In conjunction with this, MIL-STD-781C will be required in new programs for reliability development, demonstration or production acceptance tests. If MIL-STD-781 continues to influence the EBI environment as in the past, the trend will shift away from <u>stimulation</u> toward the use of combined environments tests (temperature and random vibration) which <u>simulate</u> the service environment. The test methods and techniques which evolve will be selected on their ability to provide a high degree of similitude with the operational mission environment.

Which approach is superior is also unclear. simulation approach offers several benefits. First, by simu[illegible] service environments the defects precipitated in EBI woul[illegible] y represent those that would have resulted in failures d[illegible] ctual use. This minimizes the detection and correction of te[illegible] iar problems. Secondly, estimates of the service rel[illegible] y may be obtained from routine production tests vice the c[illegible] of special reliability tests. The deleterious aspects includ[illegible] eased test cost and the proliferation of aircraft-unique EBI t[illegible] equirements.

The advantage of stimulation is primarily one of cost for facilities, test development and EBI operation. However, the risk of precipitating and correcting test peculiar problems is increased.

The industry opinion appears to favor the stimulation approach. A majority (59%) believe that the effectiveness of EBI would <u>not</u> be improved if the environment were representative of actual service flight conditions. Also, while a majority (52%) indicated a belief that a combined environments test of temperature and (random) vibration is more effective than the use of both these environments separately, only 16% indicated actual experience with a combined environments screen. In addition, several respondees indicated the difference in effectiveness

between combined and separate tests was small and that the combined test would not be cost effective. Thus it appears that while industry endorses the stimulation approach there is no clear consensus regarding the overall effectiveness of combined versus separate environmental screening tests. Resolution of this issue would provide needed guidance in the future development of the EBI test process.

SECTION III

SELECTED SYSTEMS AND ENVIRONMENTAL SCREENS

Six avionics systems were used as a basis for assessing the effectiveness of their environmental screens. They included three military avionics systems used in high performance fighter aircraft and three commercial avionics systems used in large passenger aircraft. Some of the systems were functionally similar, but included a diversity of avionic types. The systems were selected based on their production volume being sufficient to provide a good data base and the availability of detailed results on environmental screening tests. The study was limited to six systems to enable a detailed analysis of each in the time available.

The military systems selected were a Head-up Display Set (HUD), an Inertial Navigation Set (INS) and an Automatic Flight Control Set (AFCS). The commercial systems were a Digital Air Data Computer (DADC), an Inertial Navigation Unit (INU) and a Flight Guidance Set (FGS).

The EBI test designs for the commercial equipment were primarily based on previous experience with similar equipment. In some cases the number of cycles used was increased or decreased based on EBI test results and field experience. In the use of the military systems, no specific requirements for EBI testing were imposed by the Government. However, the Government did require that the suppliers conduct reliability demonstration and production acceptance sample tests in accordance with MIL-STD-781B (Reliability Tests: Exponential Distribution) test level F. This standard, in addition to specifying the test environment and decision statistics, requires that any burn-in performed on the test sample must be applied to all production units. This requirement coupled with the requirement to pass the production acceptance sample test made the test environment specified in test level F a natural choice for burn-in. As shown in Section II, this practice is common throughout the industry.

The EBI design for the military equipments was the result of on-going negotiations between the prime contractor and equipment suppliers, based on: past experience, reliability demonstration test results, prime contractor production experience and user experience. These results, in addition to EBI test results, were used to provide a flexible screening design in response to program requirements and equipment experience. The evolution of the EBI test process for the Head-up Display Set is an example of this approach. The initial EBI required a 12 cycle test at the LRU level followed by an aceptance test at the set level. The changes made and the reason for the changes are listed below in chronological order.

Change	Reason
o Required last 6 cycles failure free in 12-cycle LRU burn-in	Reduce early failures at prime contractor and improve field field MTBF
o Added 8-cycle failure-free set level burn-in between 12-cycle LRU and set acceptance test	Replaced set level reliability acceptance sample test. Sample test results were not timely with concurrent production
o LRU acceptance test placed between 12-cycle LRU burn-in and 8-cycle set burn-in	Reduce failures in 8-cycle set burn-in and escapes from 12-cycle LRU burn-in
o Remove 6-cycle failure-free discipline in 12-cycle LRU burn-in	Improved field MTBF and performance in 8-cycle set burn-in

In the descriptions of the equipment which follow various names are used to describe the performance tests conducted on units at different stages in the production process. A description and purpose of these tests is provided below as an aid to understanding the total production sequence.

Acceptance Test (AT): Also referred to as ATP (Acceptance Test Procedures) is a comprehensive performance test and physical inspection conducted by the supplier to demonstrate item compliance with the requirements of the equipment specification to the customer. It is by definition the criteria which determines the adequacy of equipment performance and therefore represents the standard by which all other performance tests may be referenced. This definition applies regardless of whether the acceptance test is for an item, LRU or set.

Integration Test is the first test of an item after being assembled from its constituents parts. It is used to verify the performance of an assembled unit and usually represents a performance thoroughness comparable to the AT.

Functional Test is a performance test which is composed of a subset of the individual tests which are contained in the acceptance test. By definition it is not as thorough as the AT. The test thoroughness relative to the AT is usually between 50 and 95 percent. This test is conducted to determine unit performance when a full AT is not appropriate.

BIT: The Built-in Test (BIT) is a performance test which is mechanized within the unit itself. In general the test thoroughness is not as comprehensive as the AT.

1. HEAD-UP DISPLAY SET - The HUD provides the pilot with information concerning the attack, navigation and aircraft attitude under all selected flight conditions. Electronic data is projected onto a combining glass, focused at infinity, in the aircraft forward field of view, providing flight information for the pilot along with a continuous view of the airspace external to the cockpit.

Two HUD Line Replaceable Units (LRU's) were considered in this study: the Display Unit (DU) and the Signal Data Processor (SDP). The set also includes a motion picture camera. The SDP is a digital computer which receives information from numerous aircraft subsystems such as the Central Computer, Radar Set, etc., and converts into an appropriate format for the DU. The DU is basically a cathode ray tube (CRT) which generates the symbol display on the combining glass.

The equipment characteristics and parts count are shown in Table 5.

TABLE 5. HUD EQUIPMENT CHARACTERISTICS

Nomenclature	Display Unit (DU)	Signal Data Processor (SDP)
Equipment Type	CRT Display	Digital Computer
Function	Combining Glass Display of HUD Symbology	Process Digital Data and Provide Symbology Drive to DU
Weight (lb)	43	18
Power (W)	214	125
Volume (in.^{3})	2625	692
Parts Count:		
MICs	116	649
Transistors	103	40
Diodes	160	82
Resistors	265	187
Capacitors	252	232
Miscellaneous	69	41
Total	965	931

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The production flow for the HUD is shown in Figure 7 Initial testing (integration, twelve-cycle burn-in, LRU AT) is performed at the unit level. Other tests (eight-cycle burn-in, set AT) are performed on the system.

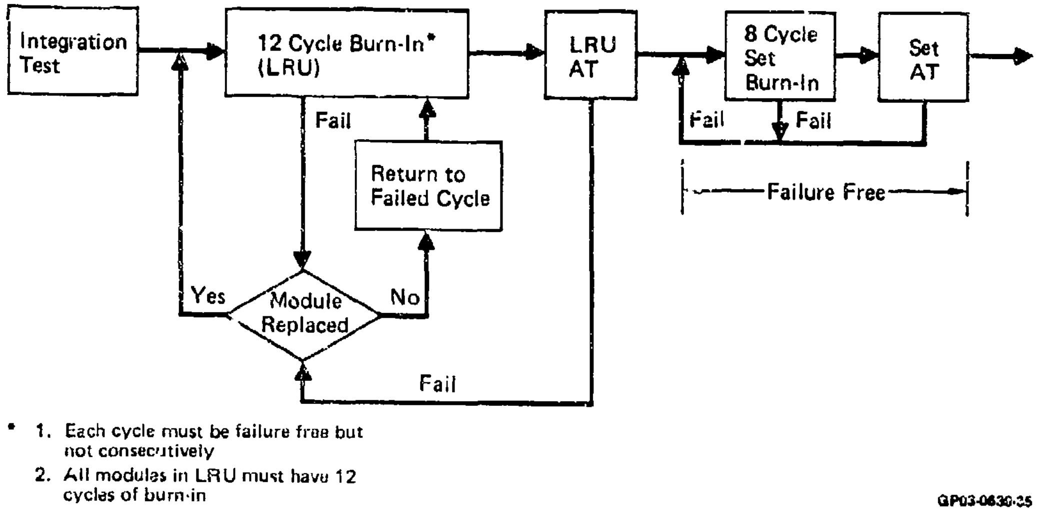
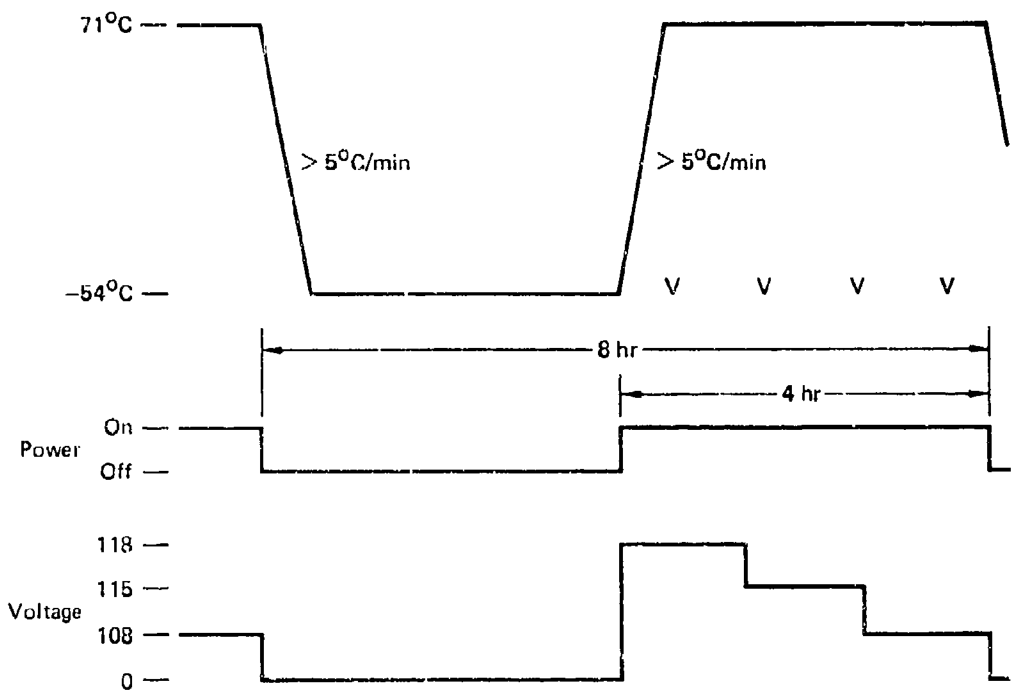


Figure 7. HUD Production Process Flow

The integration test, conducted at room ambient temperature, ensures that the unit is performing adequately. The unit is then subjected to a twelve-cycle burn-in test, as shown in Figure 8. Failed units are repaired and returned to repeat the cycle in which the failure occurred. Each unit must have twelve successful cycles although not consecutively. If the unit is repaired with a module which has not received burn-in, the unit is restarted at cycle 1. The twelve-cycle burn-in is followed by the LRU acceptance test (AT) performed at room ambient conditions. If a unit fails the AT, it returns to burn-in for one cycle (or twelve if a module is replaced).

The DU and SDP units are then tested as a system in the eight-cycle set burn-in and set AT. The set burn-in cycle is shown in Figure 9. The set must complete the eight cycles of burn-in plus the AT failure free. In case of failure the set is repaired and the set burn-in is restarted at cycle 1.

2. INERTIAL NAVIGATION SET - The Inertial Navigation Set (INS) detects aircraft motion and converts it to changes in velocity, attitude, and position. It consists of two LRU's, the Inertial Measurement Unit (IMU), and the Navigation Control Indicator (NCI). The IMU contains the sensors and digital computer for the INS functions. The sensors consist of three accelerometers and



Vibration: 1 gpk at 23 Hz for 10 min Each on Hour (V)

Performance Test: BIT Continuous When Power is On

Cooling Air: 0.37 lb/min at 80°F During Power On (SDP Only)

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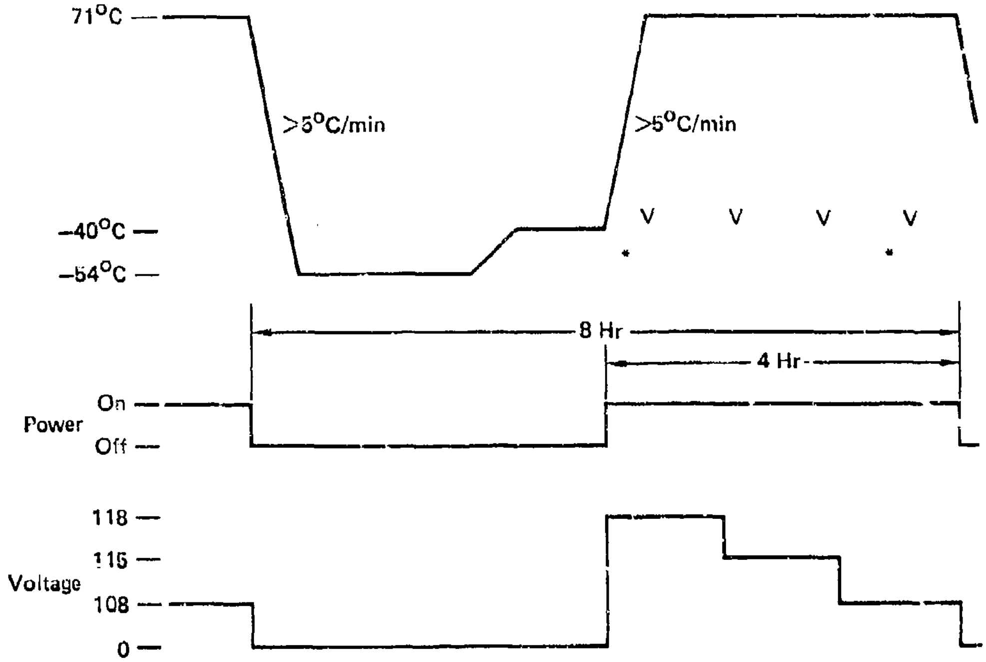
Figure 8. HUD LRU Burn-In Characteristics



Vibration: 1 gpk at 23 Hz for 10 min Each On Hour (V)

Performance Test: Functional Test Once per Cycle Alternating Hot and Cold (*)

Cooling Air Flow: 0.54 lb/min at 85°F During Power On Only

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Figure 9. HUD Set Burn-In Characteristics

two gyros, mounted on a set of four gimbals. The digital computer controls alignment sequencing, coarse and fine level, etc. It computes aircraft present position, horizontal and vertical velocity, inertial altitude and true heading. The NCI contains two digital readout windows for a display of INS data and a keyboard to insert information. The equipment characteristics and parts count are shown in Table 6.

TABLE 6. INS EQUIPMENT CHARACTERISTICS

Nomenclature	Inertial Measurement Unit	Navigation Control Indicator
Equipment Type	Inertial Platform/ Digital Computer	Digital Display/ Keyboard
Function	Provide Position and Velocity Information	Navigation Display/ Data Entry
Weight (lb)	40	8
Power (W)	249	55
Volume (in.^{3})	1700	361
Parts Count:		
MICs	1006	169
Transistors	163	3
Diodes	251	18
Resistors	940	140
Capacitors	622	96
Miscellaneous	143	46
Total	3125	472

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The production flow for the INS is shown in Figure 10. Initial tests (integration through seven-cycle burn-in) are performed at the LRU level. Acceptance test No. 1, ten-cycle burn-in, and acceptance test No. 2 are performed at the set level.

Units failing during the three-cycle or seven-cycle burn-in tests are repaired and returned to the failed cycle. Thus, each unit must pass all burn-in cycles, although not consecutively. Units failing during the ten-cycle burn-in or acceptance test No. 2 are repaired and start over, since the ten cycles and acceptance test No. 2 must be passed consecutively.

The INS burn-in procedure is shown in Figure 11. This is used for all twenty burn-in cycles. The random vibration test is described in Figure 12. The unit must pass vibration in both axes satisfactorily or the tests are repeated. The integration, vibration, and acceptance tests are all performed at room ambient temperature.

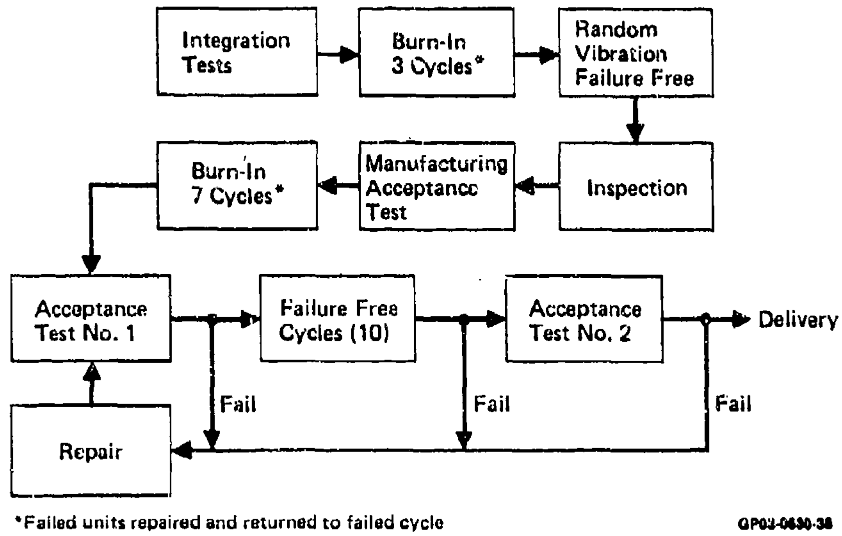

Figure 10. INS Production Process Flow

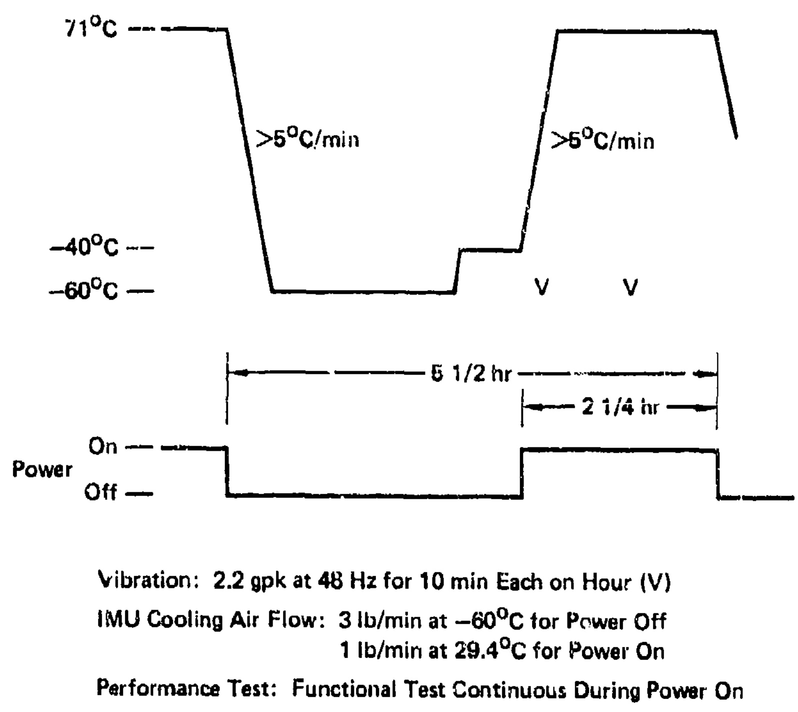

Figure 11. INS LRU and Set Burn-In Characteristics

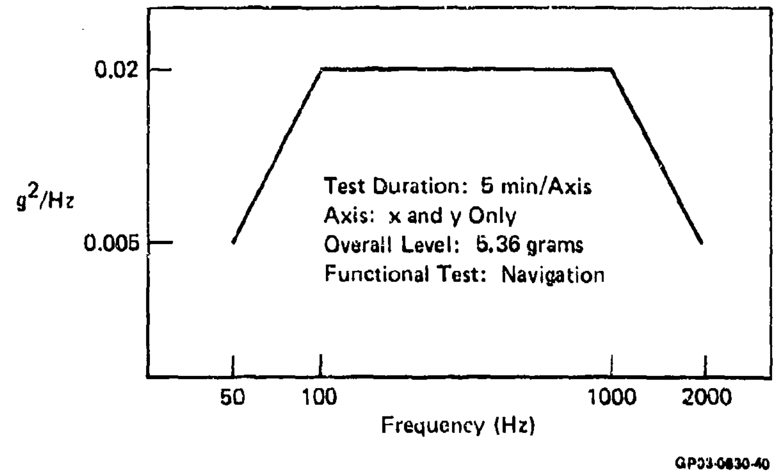

Figure 12. INS LRU Vibration Test

3. <u>AUTOMATIC FLIGHT CONTROL SET</u> - The Automatic Flight Control Set (AFCS) provides three axis command augmentation for improving the aircraft handling qualities. Attitude and altitude hold functions are also provided. The AFCS consists of seven LRU's. The Pitch Computer processes inputs from other AFCS components and aircraft systems to compute the outputs to the stabilator actuators. The Roll/Yaw Computer performs a similar function for outputs to the stabilator and rudder actuators. The engaging controller (EC) contains mode switches for pilot interface with the AFCS. The accelerometer assembly contains four accelerometers, each sensor providing an output signal proportional to aircraft acceleration along the two sensitive axes (normal, lateral). The rate gyro assembly contains six gyros, two for each of the axes. The stick force sensor (SFS) contains strain gage elements to measure pilot forces applied to the control stick. A dynamic pressure sensor is also provided but was not included in the study because the burn-in is conducted primarily for aging the unit rather than to detect quality defects. The equipment characteristics and parts count are shown in Table 7.

The production process flow for the AFCS is shown in Figure 13. As seen in the figure, three processes are used to produce the six LRU's. The pitch and roll/yaw computers use a nine-cycle burn-in followed by an LRU acceptance test conducted at room ambient. The burn-in is shown in Figure 14. The last three cycles must be consecutively failure free. If a unit fails in cycles 7, 8 or 9, it is repaired and returned to test until three consecutive failure-free cycles are obtained. If a failure occurs in cycles 1 through 6 with the unit at cold temperature, it is returned to test at the failed cycle. If the failure occurs at hot temperature, it is returned to the next cycle.

TABLE 7. AFCS EQUIPMENT CHARACTERISTICS

Nomenclature	Pitch Computer	Roll/Yaw Computer	DPS	EC	Accelerometer	Gyro	SPS
Equipment Type	Analog Computer	Analog Computer	Pressure Transducer	Switch Panel	Pendulum Accelerometer	Rate Gyro	Strain Gage Assembly
Function	Aerodynamic Calculations	Aerodynamic Calculations	Measure Dynamic Pressure	Unit Control	Measure Vortical/ Lateral Accelerations	Measure Pitch Roll and Yaw Rates	Measure Stick Forces
Weight (lb)	12.7	14.9	1.4	2.0	1.8	6.8	3.1
Power (W)	34	45	0.26	12	1.0	4	0.5
Volume ($in.^3$)	540	540	67	96	48	183	58
Parts Count:							
MICs	87	120	1	0	4	0	4
Transistors	51	82	0	0	0	0	0
Diodes	94	98	1	4	1	1	0
Resistors	599	724	5	21	13	6	19
Capacitors	147	206	0	23	4	3	18
Miscellaneous	16	17	0	3	0	0	4
Total	994	1246	8	51	22	10	55

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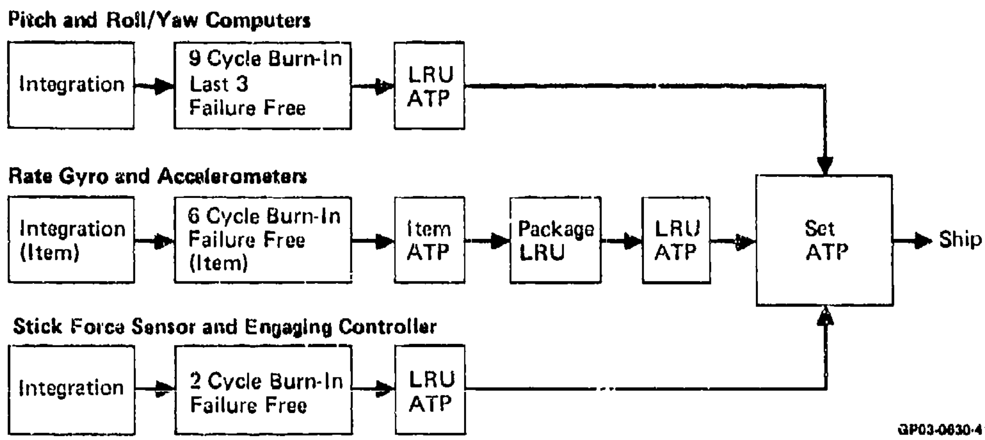
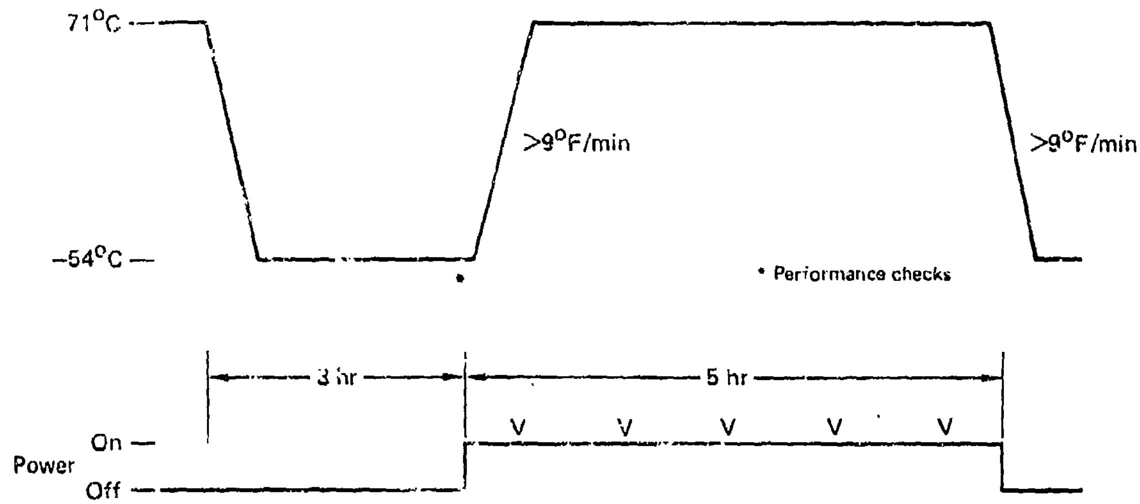


Figure 13. AFCS Production Process Flow



Vibration: 1.67 g (0.036 in. DA) at 30 ± 3 H 10 min Each on Hour (V)

Line Voltage: Cycle 1, 4, 7 104 VAC, 25 VDC
Cycle 2, 5, 8 115 VAC, 28 VDC
Cycle 3, 6, 9 126 VAC, 31 VDC

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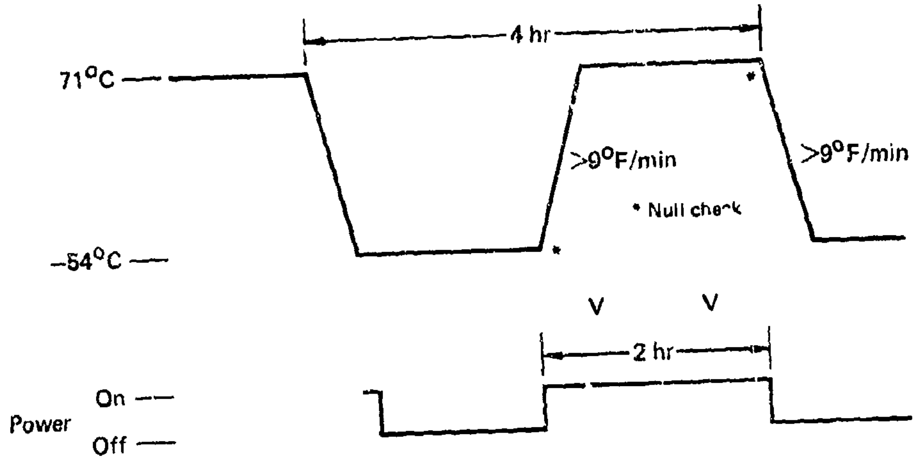
Figure 14. Pitch and Roll/Yaw Computer Burn-In Characteristics

The rate gyros and accelerometers are burned in at the item level, prior to assembly as an LRU. The burn-in characteristics are depicted in Figure 15. The burn-in discipline requires consecutive failure-free performance of six cycles plus fail free performance of an ambient performance test after the third and sixth cycles. The unit performance requirements are tightened after the third cycle.

The SFS and EC burn-in cycle is shown in Figure 16. It must be completed without failure. If a failure occurs, the test is repeated.

4. <u>INERTIAL NAVIGATION UNIT</u> - The Inertial Navigation Unit (INU) provides position information, course-line computation, steering commands, heading information, etc. The unit contains a four gimbal, gyro stabilized platform in conjunction with a general purpose digital computer. Equipment characteristics are shown in Table 8.



Vibration: 1.67 g (0.036 in. DA) at 30 ± 3 Hz for 10 min
Each on Hour (V)

Performance Tests: Null Checks Every Cycle
Full Performance Check at: Cycle 1 Cold Only
Cycle 2
1st Ambient
Cycle 6
2nd Ambient

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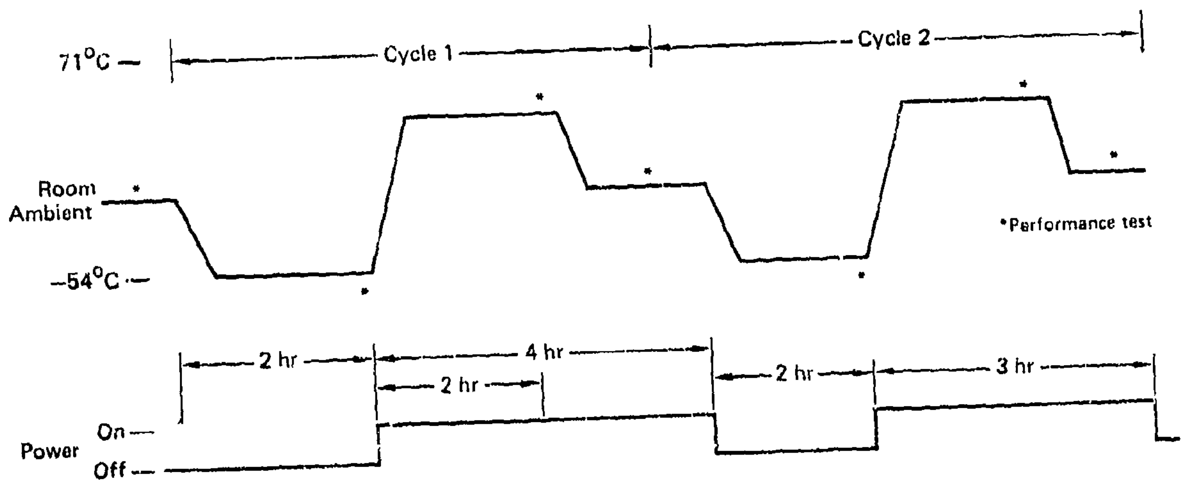
Figure 15. Rate Gyro and Accelerometer Burn-In Characteristics



Vibration: 1.65 g (0.036 in. DA) at 30 ± 3 Hz Applied for 10 min
6 Times During the Burn-In Cycle

GP03-0814-9

Figure 16. SFC and EC Burn-In Characteristics

TABLE 8. INU EQUIPMENT CHARACTERISTICS

Nomenclature		Inertial Navigation Unit
Equipment Type		Inertial Platform/Digital Computer
Function		Provide Position and Velocity Information
Weight	(lb)	59
Power	(W)	230
Volume	(in.^{3})	1743
Parts Count:		
MICs		807
Transistors		394
Diodes		560
Resistors		1888
Capacitors		649
Miscellaneous		239
Total		4537

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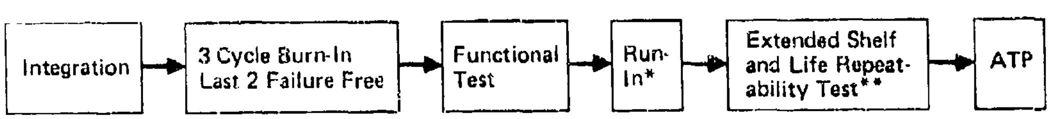
Significant features of the INU production process are shown in Figure 17. All testing other than burn-in is performed at room ambient temperature. The burn-in consists of three cycles, of which the last two must be consecutively failure free. The cycle used for burn-in is described in Figure 18. If the unit fails in Cycle 1, it is repaired and returned to test at Cycle 1.

5. <u>FLIGHT GUIDANCE SET</u> - The Flight Guidance Set (FGS) electronics consists of three analog computers that perform the computations for the autopilot. There is one computer each for the pitch, roll, and yaw axes. Equipment characteristics for the computers are listed in Table 9.



* Room ambient power on for ≈ 12 hr

** Retest after 48 hr storage at room ambient

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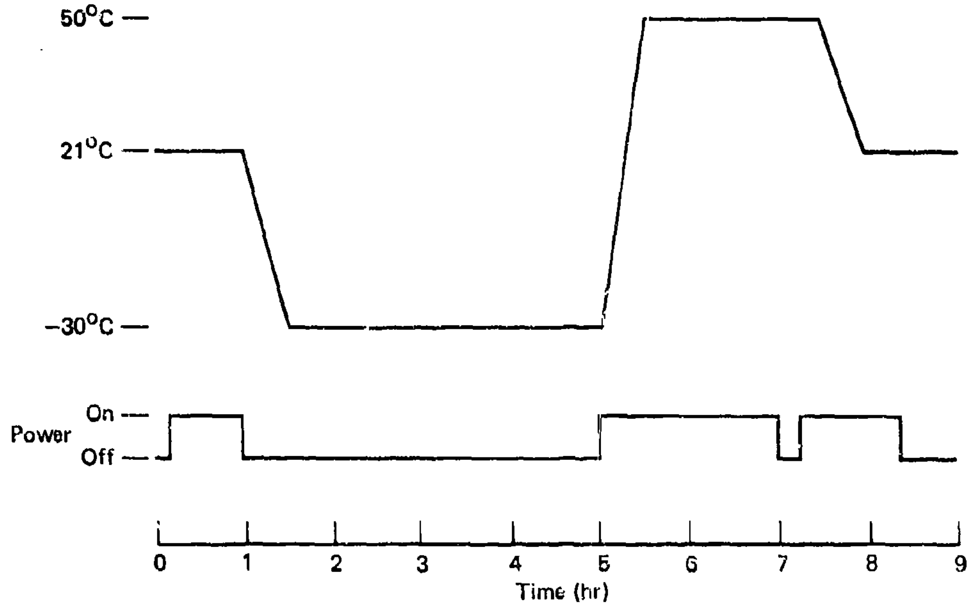
Figure 17. INU Production Process



Vibration: None

Cooling Air: 4 lb/min at Chamber Temperature

Performance Test: Continuous Functional Test During Power On

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Figure 18. INU Burn-In Characteristics

TABLE 9. FGS COMPUTER CHARACTERISTICS

Nomenclature	Pitch Computer	Roll Computer	Yaw Computer
Equipment Type	Analog Computer	Analog Computer	Analog Computer
Weight (lb)	45	40	27
Power (W)	181	174	94
Volume (in.^{3})	1690	1690	1690
Parts Count:			
MICs	884	783	483
Transistors	274	218	150
Diodes	796	627	450
Resistors	2088	1592	1110
Capacitors	616	513	394
Relays	159	129	55
Miscellaneous	45	32	40
Total	4872	3894	2682

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The FGS production process flow is depicted in Figure 19. All events other than the sixteen-cycle burn-in are conducted at room ambient temperature. The burn-in cycle characteristics are shown in Figure 20. Units in the burn-in are performance tested once per day (every four cycles). After failure, a unit is repaired and returned to burn-in at the cycle following that in which the failure was observed.

6. <u>DIGITAL AIR DATA COMPUTER</u> - The Digital Air Data Computer (DADC) is a single unit composed of pressure transducers and associated electronics to perform required computations. The DADC computes air speed, Mach number, and altitude rate from the total and static pressure. Equipment characteristics and parts count are shown in Table 10.

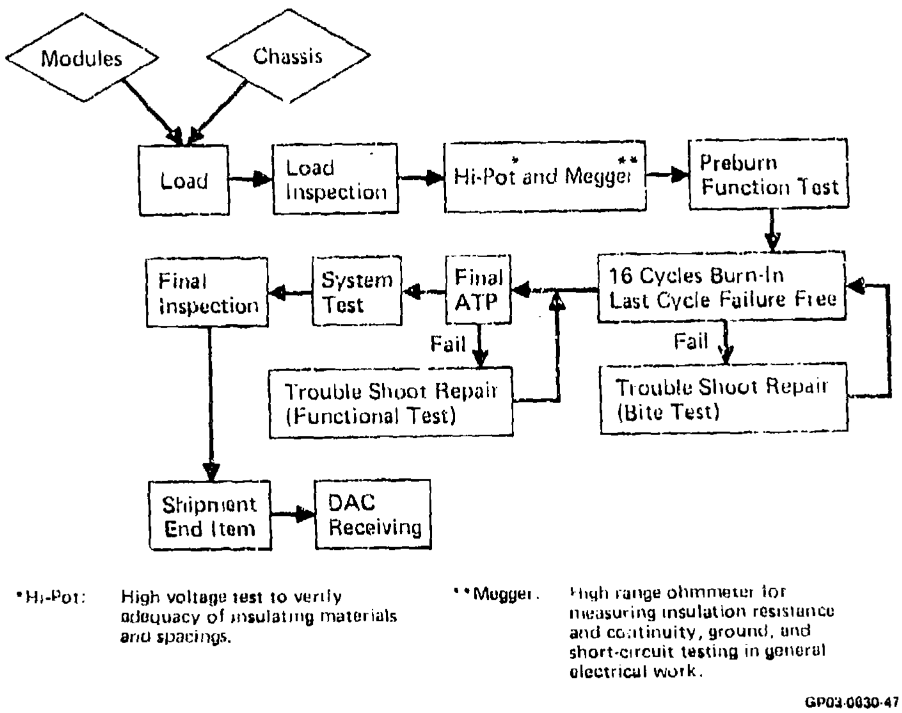


Figure 19. FGS Production Process Flow

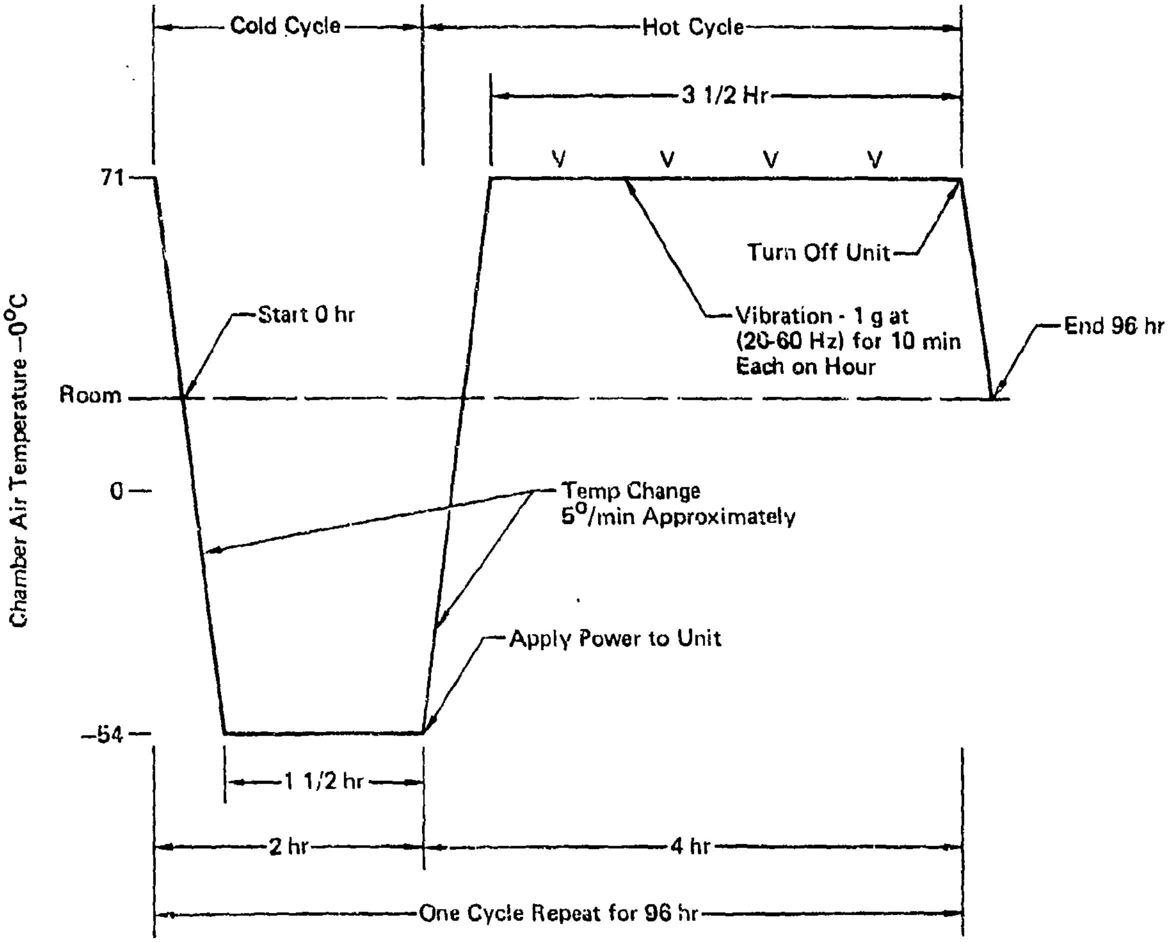


Figure 20. FGS Computer Burn-In Characteristics

TABLE 10. DADC EQUIPMENT CHARACTERISTICS

Nomenclature	Digital Air Data Computer
Equipment Type	Digital Computer
Function	Compute Airspeed, Mach Number and Altitude Rate
Weight (lb)	19
Power (W)	116
Volume ($in.^3$)	525
Parts Count:	
MICs	440
Transistors	127
Diodes	87
Resistors	558
Capacitors	127
Miscellaneous	169
Total	1600

GP03-0814-7

The DADC production process flow is shown in Figure 21 and the burn-in characteristics in Figure 22. Performance testing during burn-in is conducted once every four cycles at room ambient temperature. All modules in a unit must have a minimum of three cycles prior to completion of the burn-in. Units failing the acceptance test are repaired and returned to burn-in for one cycle, which must be failure-free.

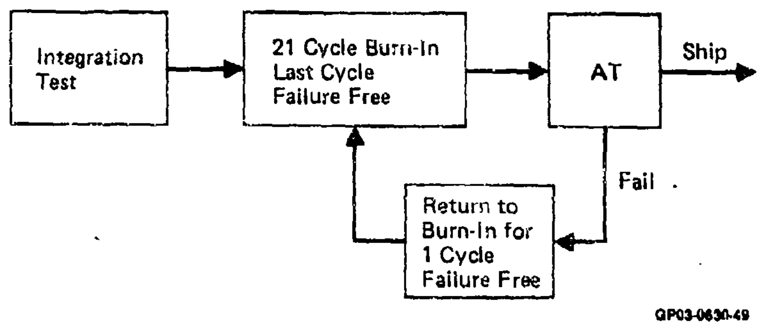


Figure 21. DADC Production Process Flow

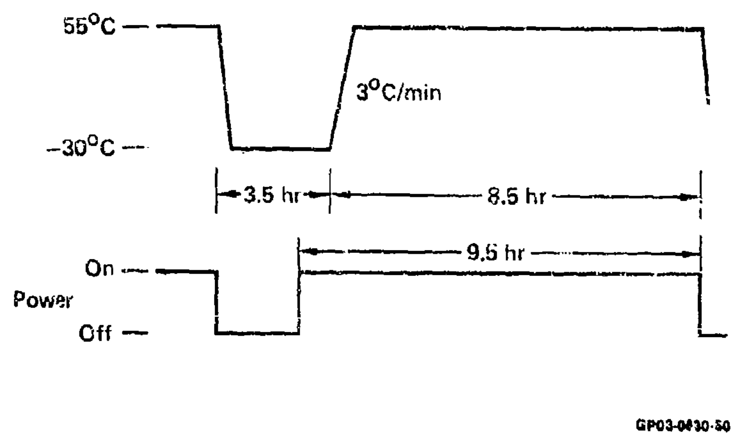


Figure 22. DADC Burn-In Cycle Characteristics

SECTION IV

ENVIRONMENTAL BURN-IN RESULTS AND ANALYSIS

Analysis of the environmental burn-in (EBI) tests shows that the selected LRU's display four common attributes: 1) a decreasing failure rate in the first few cycles (reliability improvement), 2) a relatively constant failure rate subsequently (no reliability improvement), 3) a "reburn-in" characteristic for failed units (reliability improvement after failure and repair), and 4) a relatively large acceptance test failure rate at the end of EBI (performance test in EBI not as thorough as AT).

The EBI results were used to estimate the parameters of the burn-in model of Appendix A. The capability of the model to characterize the diverse failure rates encountered in practice was demonstrated with several examples. The burn-in effectiveness measures are provided for the subject equipments. One of the effectiveness measures, the produced fraction defective (PFD) was shown to be highly correlated with the unit part count. The study also indicates that failure analysis activity should generally be concentrated on the failures which occur in the early cycles of burn-in.

The overall failure rate was categorized by type of defect (part, workmanship. etc). This indicated that the reliability improvement provided by EBI is primarily due to the removal of defective parts. Further breakdown by part class (IC, capacitors, resistors, etc.) shows that the part failure rate is primarily due to IC's.

The distribution of failures among defect type and part class was examined versus failure number (1, 2, ...) and EBI test. These distributions did not vary significantly. However, there is some indication that the distribution of defect types is different for random vibration tests vice the temperature cycling EBI.

1. <u>OVERALL FAILURE RATES</u> - The overall discrete failure rate (r_j) is estimated from the test results using Equation (A-14) from Appendix A. The term overall means that all failures of the equipment are included except induced failures caused by test equipment and/or operator error. Incidents which indicate a failure during test but later recheck okay (ROK) or cannot be duplicated (CND) are included in the overall assessment. The statistical test used to test the hypothesis that the failure rate is constant during burn-in was the ubiquitous Chi-Square test for homogeneity found in most elementary statistics texts (ref. Breiman, Duncan). If the test rejects homogeneity and the point estimates ($\hat{r}_j$) decrease with cycle, the failure rate was classified as decreasing.

The failure rate was estimated for the time ordered failures of the units. The failure rate for first failure was taken as the probability of a unit having its first failure in a cycle given

the unit has not failed any previous cycles. The failure rate for second failure was similarly defined as the probability of failing a cycle (j) given the unit has survived (j-1) previous cycles since the first failure. The failure rate for third failure is analogously defined.

Thus, the failure rate for first failure characterizes the initial behavior of the population of all units in the burn-in process. The values of this failure rate at the end of burn-in (last few cycles) may be viewed as an estimate of the failure rate of the surviving population. In the case of the failure rate for first failure, the surviving population has completed the burn-in with no failures. Similarly the failure rate for the second failure characterizes the behavior of the unit population after one failure and repair. The values of the failure rate in the last cycles may be viewed as an estimate of the failure rate for units which pass burn-in with one failure. The failure rate for third, fourth etc., failure can be viewed in a similar fashion. The number of units which fail three or more times is usually small compared to the total population, limiting meaningful statistical analysis.

a. <u>HUD Display Unit</u> - The overall discrete failure rate ($\hat{r}_j$) for the HUD DU cycle to first failure is shown in Figure 23. The 95% confidence bounds are also shown. As seen in the figure, the failure rate appears to decrease rapidly after the first cycle and approach a steady state value after the third cycle. A Chi-Square test for homogeneity in cycles 1 through 12 yields a $\chi^2_{(11)} = 32.6$ versus a critical value of 19.7 for $\alpha = .05$. This indicates that the failure rate is not constant (reject homogeneity). However, a test for homogeneity of cycles 2 through 12 does not reject at $\alpha = .05$. ($\chi^2_{(10)} = 7.72 < \chi^2_{(10)(.05)} = 18.3$). Based on the above tests and the point estimates ($\hat{r}_j$) it is assumed that the failure rate is decreasing.

The failure rate for the acceptance test (AT) is 0.191 indicating that approximately one-fifth of the units which survive the burn-in without failure subsequently fail the acceptance test. Since the acceptance test and burn-in cycle are of comparable duration, the high AT failure rate appears to be caused by the difference between the performance test requirements in burn-in vice the acceptance test. Because of this performance test disparity, a unit's failure during burn-in can go undetected until the acceptance test. Similarly, if the "undetectable" failure is temperature sensitive (only fails when the ambient temperature is hot or cold) the failure may pass the acceptance test undetected, since the AT is conducted at room temperature. This high AT failure rate is clearly undesirable.

The large number of failures in the AT indicate the EBI failure rate estimates may be biased. The degree of bias depending on the number of AT failures which actually occurred in EBI and where in the EBI test they occurred. These facts are unknown. Due to the large sample size, the relative values of the

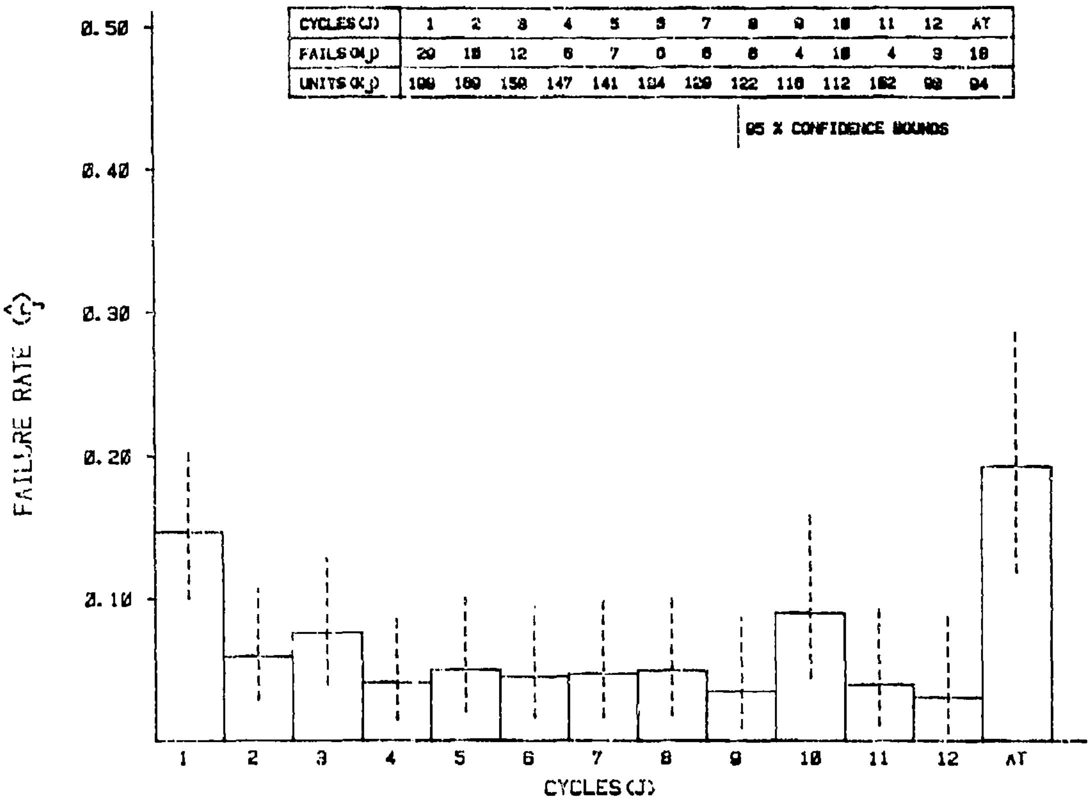
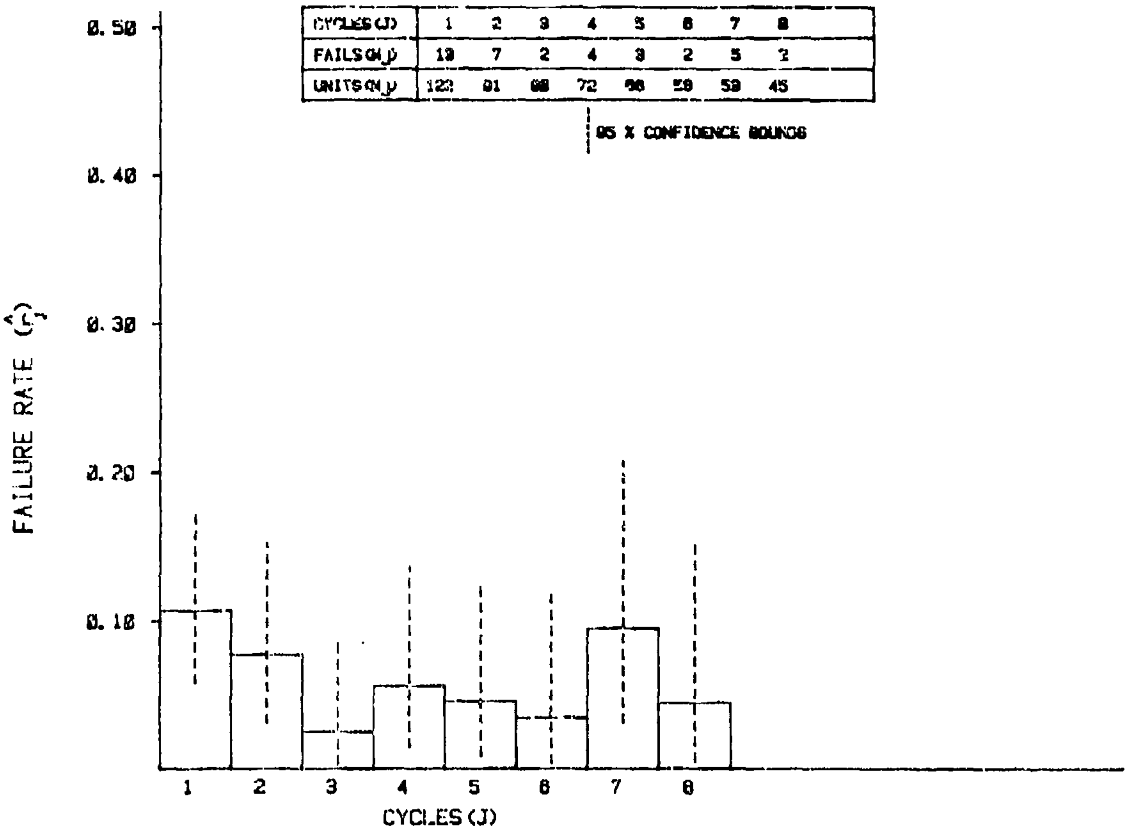


Figure 23. HUD DU Overall Failure Rate for First Failure (12 Cycle Burn-In)

EBI estimates are not affected by the unknown bias. Thus the existing estimates provide an accurate representation of the temporal behavior of the EBI failure rate. For this reason, and to facilitate comparison with other EBI failure rates without AT results, assumptions concerning the AT failures were not considered appropriate. Therefore, no correction of EBI failure rate based on AT failures was used.

The overall failure rate for the cycle between first and second failure is shown in Figure 24. Due to the small sample, the confidence bounds are quite wide. Although the failure rate appears to decrease initially (cycles 1 thru 6), the hypothesis of homogeneity of failure rate (cycles 1-8) cannot be rejected in a Chi-Square test at $\alpha = .05$ ($\chi^2_{(7)} = 8.29 < \chi^2_{(7)(.05)} = 14.1$). Due to the small sample size little detection capability is provided by statistical tests. But from Figure 24, it appears that the failure rate initially decreases and then becomes constant after the second cycle.



CYCLES (J)	1	2	3	4	5	6	7	8
FAILS (X_j)	13	7	2	4	3	2	5	2
UNITS (N_j)	123	91	68	72	66	58	53	45

Figure 24. HUD DU Overall Failure Rate for Second Failure (12 Cycle Burn-In)

Figures 25 and 26 are the overall failure rates for the DU in the eight-cycle failure-free burn-in for the first and second failures respectively. The eight-cycle burn-in is conducted at the set level (DU & SDP) on units which have completed the twelve-cycle LRU Burn-in and AT. Referring to Figure 25, again as in Figure 23, the failure rate decreases rapidly after the first cycle appearing to be relatively constant in Cycles 2 through 8. In a Chi-Square test for homogeneity of failure rate for Cycles 1 through 8, the hypothesis of constant failure rate is rejected ($\chi^2(7) = 23.4 > \chi^2(7)(.05) = 14.1$). Thus, it is reasonable to assume that the failure rate is decreasing in Figure 25. Again as in Figure 23, a high failure rate for units which survive the burn-in is observed for the acceptance test.

Figure 26 shows the failure rate for units which have had one failure in the burn-in. Again, the small sample (65 units) limits the detectability of statistical tests. However, from the point estimates ($\hat{r}_j$) it appears that, as before, the failure rate initially decreases (Cycle 1-2) and then remains relatively constant (Cycles 2-8). The high AT failure rate is again present.

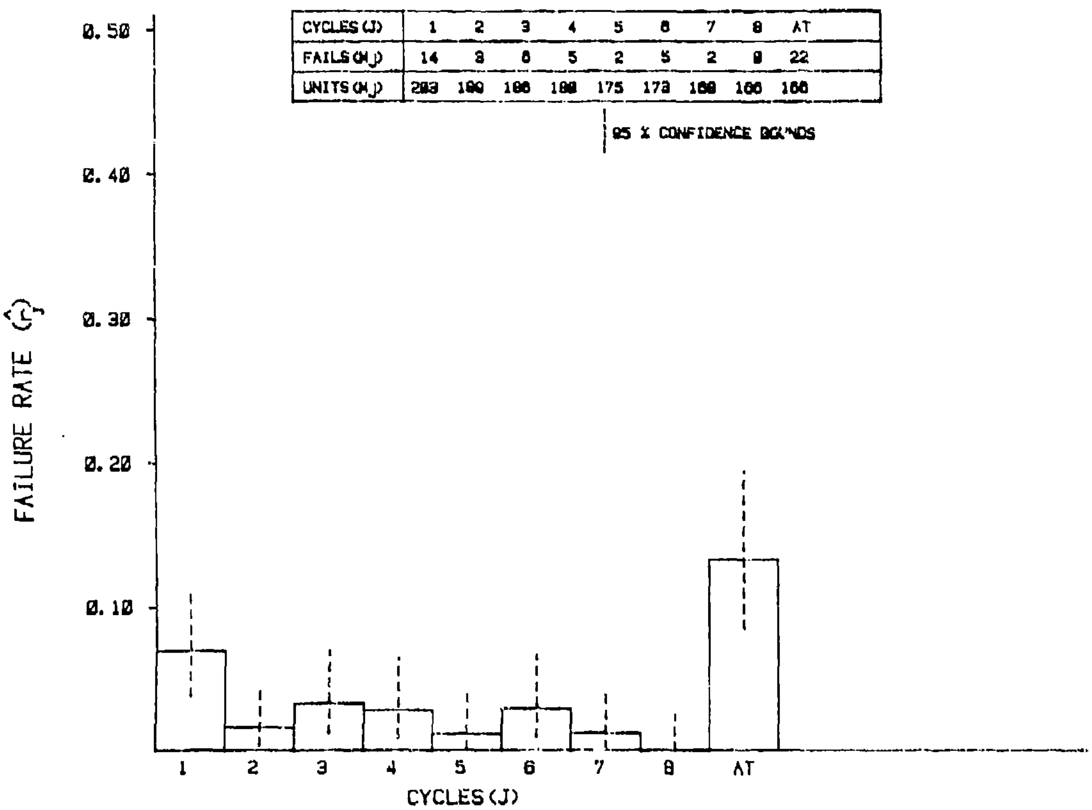


Figure 25. HUD DU Overall Failure Rate for First Failure (8 Cycle Burn-in)

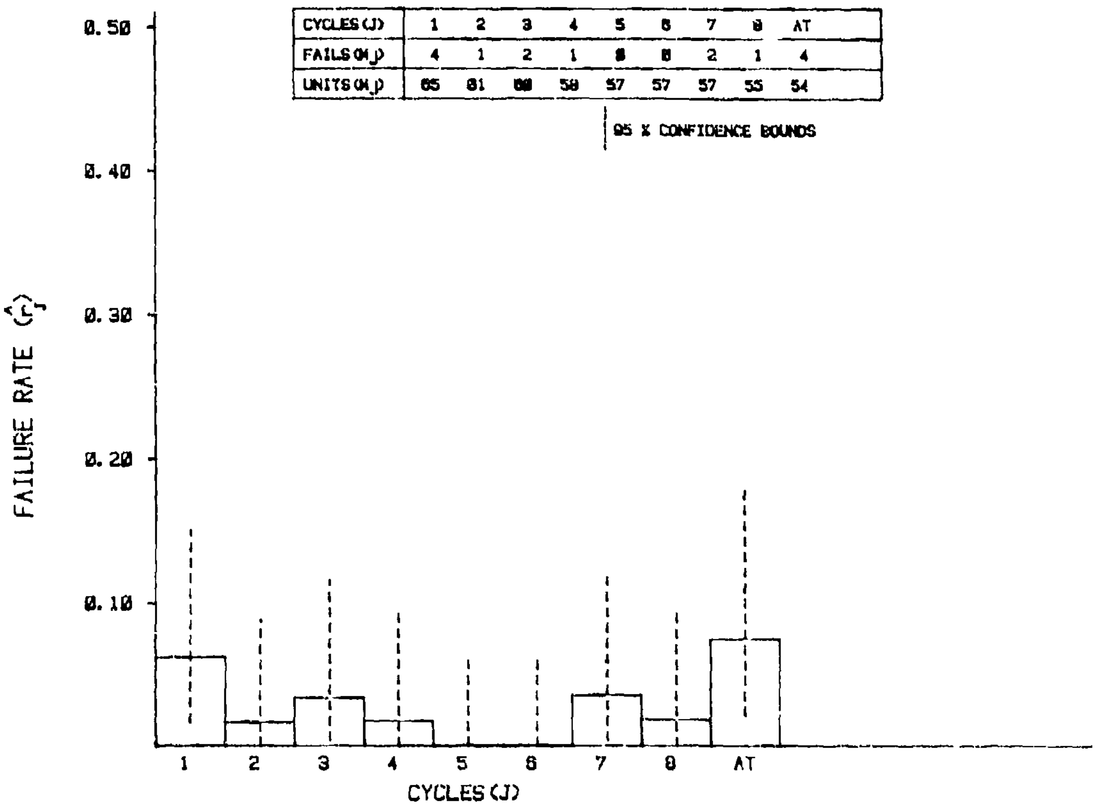
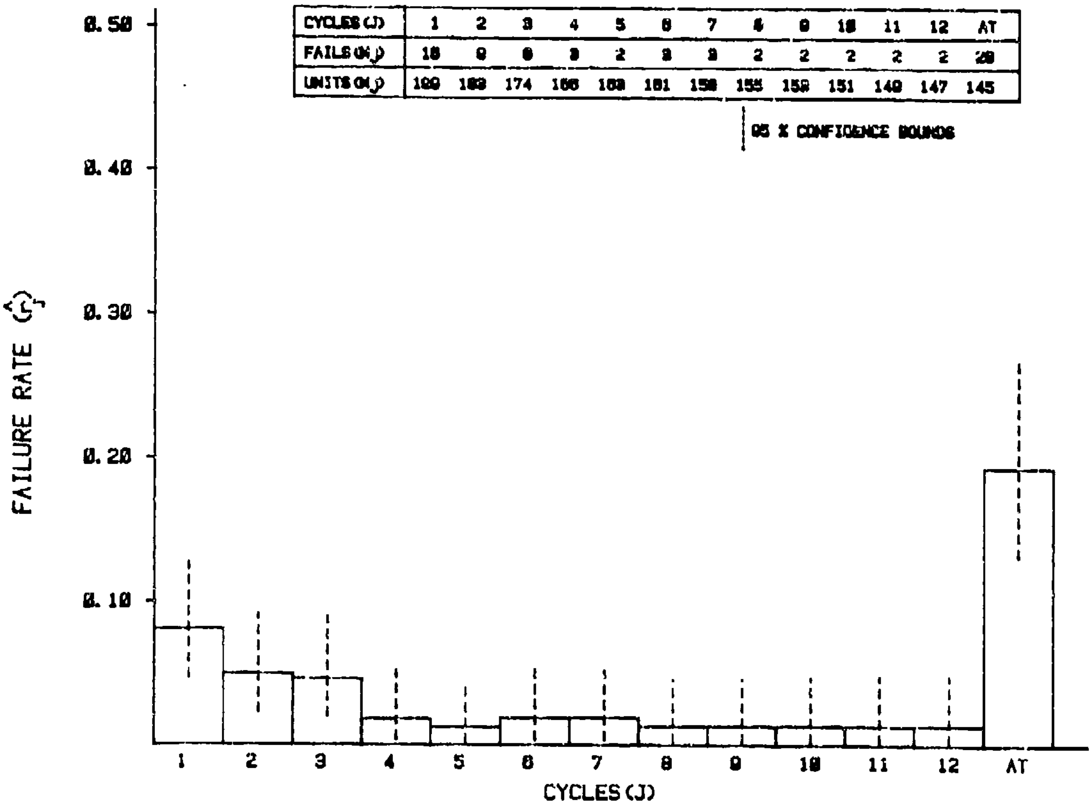


Figure 26. HUD DU Overall Failure Rate for Second Failure (8 Cycle Burn-In)

b. <u>HUD Signal Data Processor</u> - The HUD Signal Data Processor (SDP) failure rate for first failure in the twelve cycle LRU burn-in is shown in Figure 27. The point estimates ($\hat{r}_j$) decrease for the first three cycles, becoming relatively constant from the fourth to twelfth cycle. The hypothesis of constant failure rate for cycles 1 through 12 is rejected in a Chi-Square test ($\chi^2_{(11)} = 34.8 > \chi^2_{(11)(.05)} = 19.7$) for $\alpha = .05$. The hypothesis of constant failure rate for cycles 2 through 12 is not rejected, however ($\chi^2_{(10)} = 14.9 < \chi^2_{(10)(.05)} = 18.3$). The overall failure rate for first failure is classified as decreasing. As in the burn-in of the DU discussed in the last section, the AT failure rate is relatively large compared to the burn-in cycles, indicating a disparity in performance test criteria in AT versus burn-in.



CYCLES (J)	1	2	3	4	5	6	7	8	9	10	11	12	AT
FAILS (K,J)	16	9	8	3	2	3	3	2	2	2	2	2	28
UNITS (N,J)	199	183	174	166	163	161	158	155	153	151	149	147	145

Figure 27. HUD SDP Failure Rate for First Failure (12 Cycle Burn-In)

The failure rate for second failure is shown in Figure 28. As observed in previous examples, the failure rate decreases for the first few cycles. A Chi-Square test for homogeneity of cycles 1-12 does not reject, however. If the observations are pooled by cycle adjacent pairs (1 and 2, 3 and 4, etc.) and again tested for constant failure rate, the Chi-Square test rejects the hypothesis of homogeneity ($\chi^2(5) = 13.66 > \chi^2(5)(.05) = 11.1$). The failure rate for second failure is also decreasing.

The HUD SDP failure rate in the eight-cycle set burn-in is shown in Figures 29 and 30. The failure rate for first failure (Figure 29) is decreasing. Homogeneity tests for cycles 1-8 and 2-8 both reject homogeneity for $\alpha = .05$ ($\chi^2(7) = 36.9 > \chi^2(7)(.05)$ and $\chi^2(6) = 14.6 > \chi^2(6)(.05)$).

Contrary to the 12-cycle burn-in experience, the AT failure rate is not large relative to the cycle failure rate. It appears that the performance test for the SDP in set burn-in is comparable in thoroughness to the set acceptance test. The failure rate for second failure is shown in Figure 30. From the point estimates the failure rate appears to be decreasing, although the Chi-Square test for homogeneity does not reject ($\chi^2(7) = 5.98 < \chi^2(7)(.05)$).

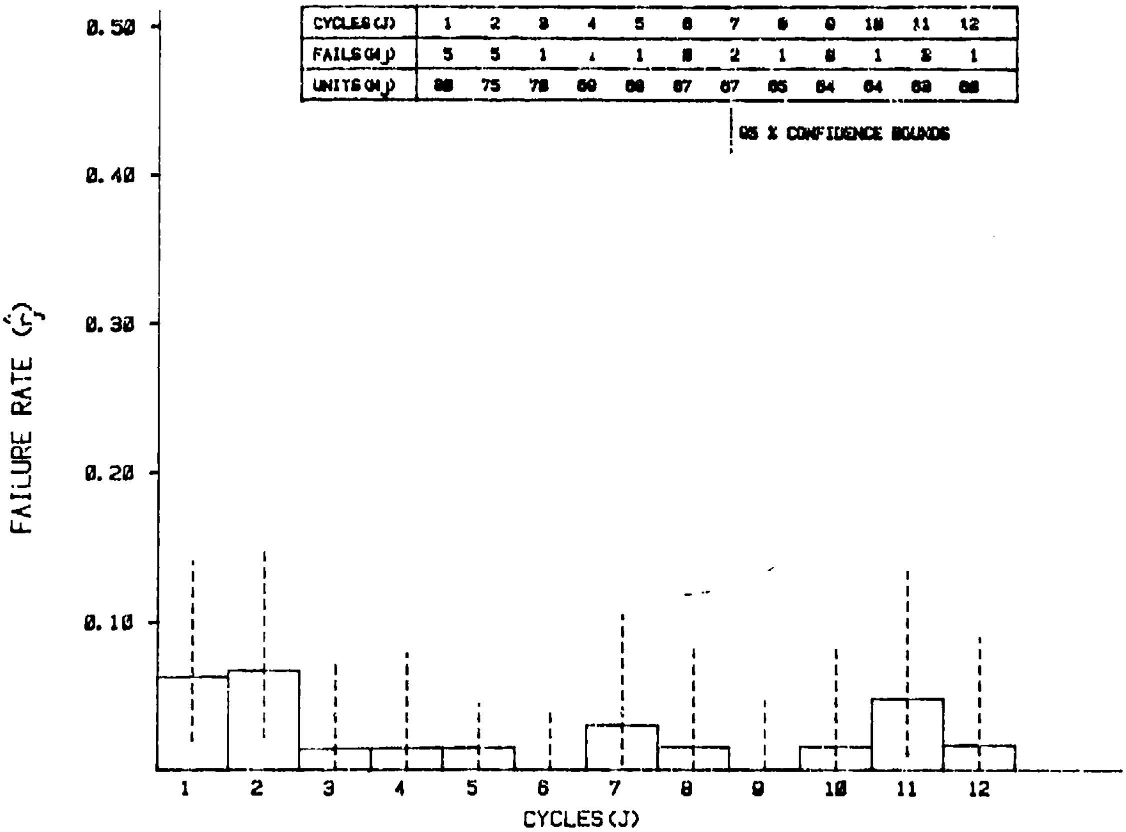


Figure 28. HUD SDP Failure Rate for Second Failure (12 Cycle Burn-In)

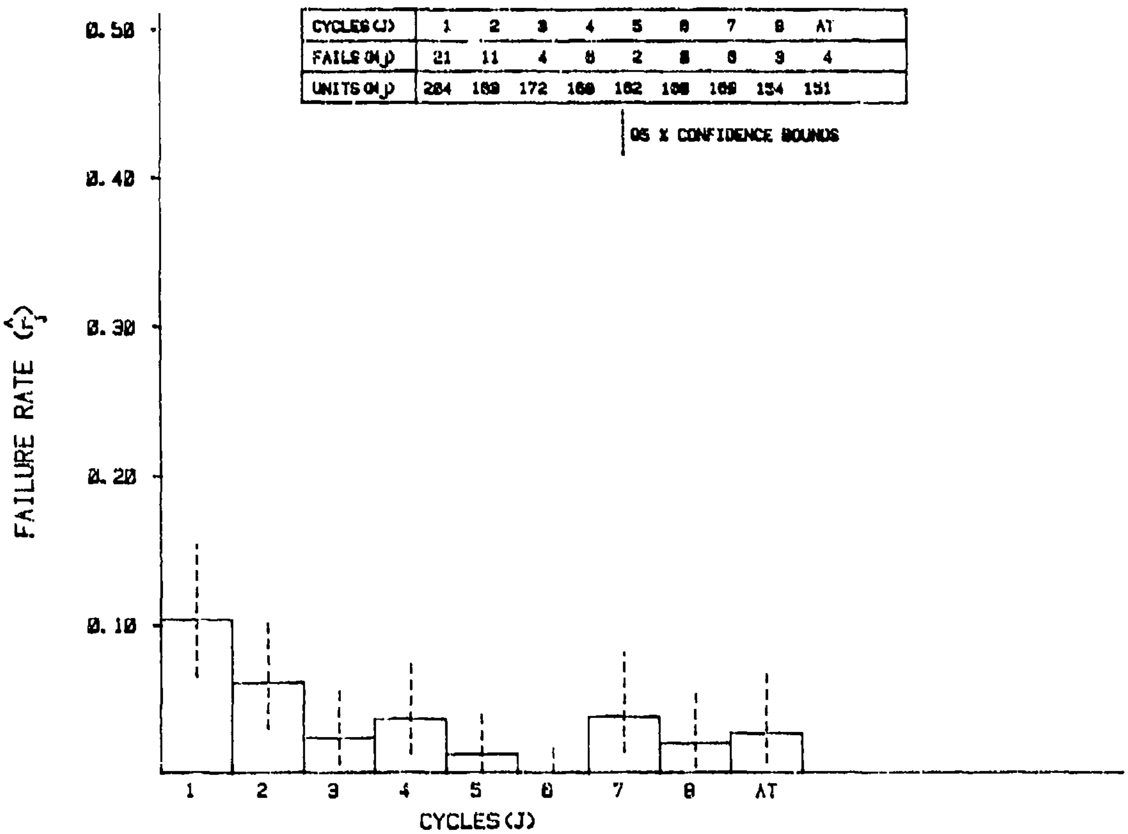


Figure 29. HUD SDP Failure Rate for First Failure (8 Cycle Burn-In)

c. INS Inertial Measurement Unit - The Inertial Measurement Unit (IMU) production test sequence contains three separate burn-in sequences of different length as described previously in Figure 4. They are referred to as the three-cycle, seven-cycle and ten-cycle burn-in tests.

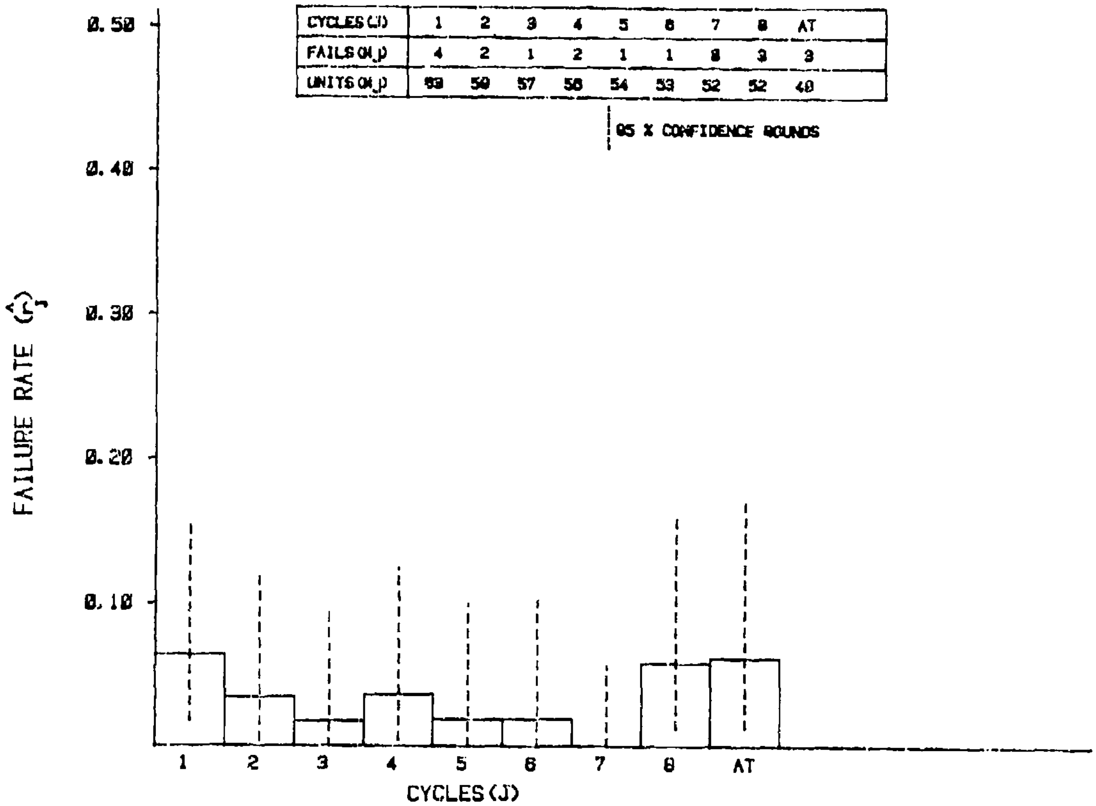


Figure 30. HUD SDP Failure Rate for Second Failure (8 Cycle Burn-In)

Figures 31, 32 and 33 depict the failure rate for the first, second and third failures for the three-cycle burn-in. Results are shown for four cycles, since many units receive an additional cycle before the three-cycle test.

There is a significant decrease in the failure rate from the first to second cycle for all failure rates. Statistical tests for homogeneity of failure rate reject for all three cases:

1st Failure $\chi^2(3) = 109.2 > \chi^2(3)(.05) = 7.81$

2nd Failure $\chi^2(3) = 39.7 > \chi^2(3)(.05) = 7.81$

3rd Failure $\chi^2(3) = 12.9 > \chi^2(3)(.05) = 7.81$

It is clear that most of the reliability improvement (decrease in failure rate) is accomplished in the first test cycle, either initially (Figure 31) or after failure and repair (Figures 32 and 33). After the first cycle, the failure rate appears either to decrease slowly or remain relatively constant.

The relatively large failure rate after failure and repair represents two distinct phenomena: multiple defects in a unit and imperfect repair. There are three sources of imperfect repair. After failure, burn-in units are repaired at what is commonly

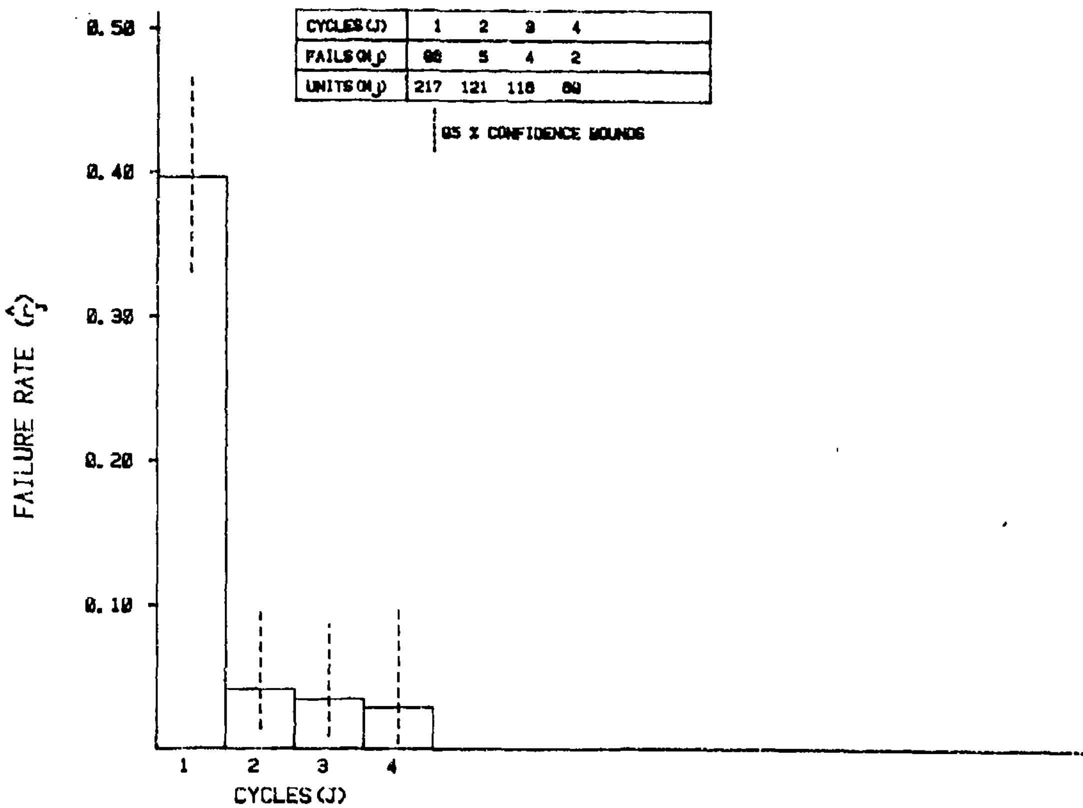


Figure 31. INS IMU Failure Rate for First Failure (3 Cycle Burn-In)

referred to as the card or module level. That is, units are repaired by replacing unit subassemblies (cards or modules) rather than replacing the defective piece parts in the card or module. This is usually done to expedite the unit's return to the burn-in test. But in some cases, the replacement module may also be defective. This is understandable since in early burn-in the replacement modules are samples from the same population (no burn-in) of modules which are initially installed in units. In other cases, the module replaced is not responsible for the failure observed in the burn-in. The unit will then fail when returned to burn-in since the original failure has not been removed. Especially in the case of environmentally sensitive components this aspect is not uncommon. It may require several repairs and retests to identify the actual source of failure. The third source of imperfect repair is the repair activity itself. During repair, additional defects may be created: cards may be loosened, connector pins bent, parts inadvertently damaged, etc.

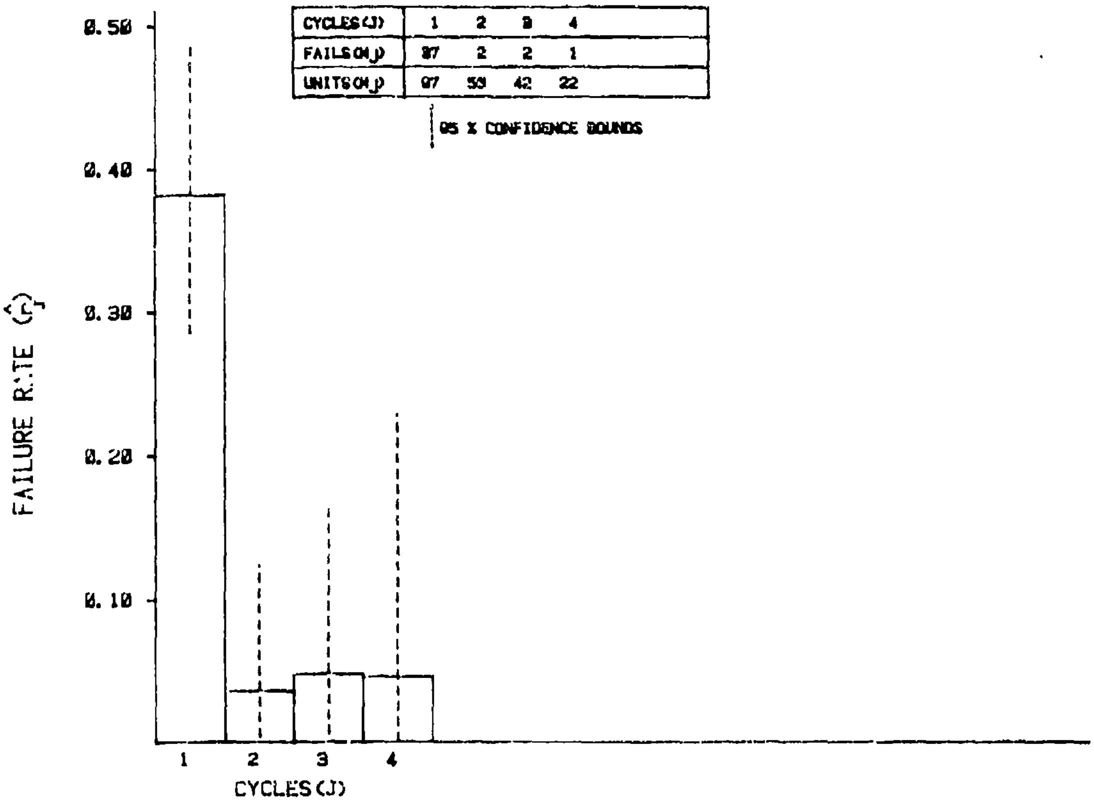


Figure 32. INS IMU Failure Rate for Second Failure (3 Cycle Burn-In)

The high but decreasing failure rate after repair is referred to as "reburn-in". Referring to the previous section on the HUD, Figures 24, 26, 28 and 30 show the reburn-in process, although less pronounced than in the case of the IMU.

Figures 34 and 35 show the IMU failure rate for first and second failures in the seven-cycle burn-in. As in the previous examples, both failure rates decrease from first to second cycle and remain relatively constant from the second cycle until the end of burn-in. As in the three-cycle test, the reburn-in phenomenon is present as evidenced by the relatively large failure rate after repair (Figure 35) as compared to initial burn-in (Figure 34). The Chi-Square test for homogeneity of failure rate is rejected for both failure rates. The values are:

1st Failure $\chi^2(6) = 16.2 > \chi^2(6)(.05) = 12.6$

2nd Failure $\chi^2(6) = 22.0 > \chi^2(6)(.05) = 12.6$

Thus both failure rates would be classified as decreasing.

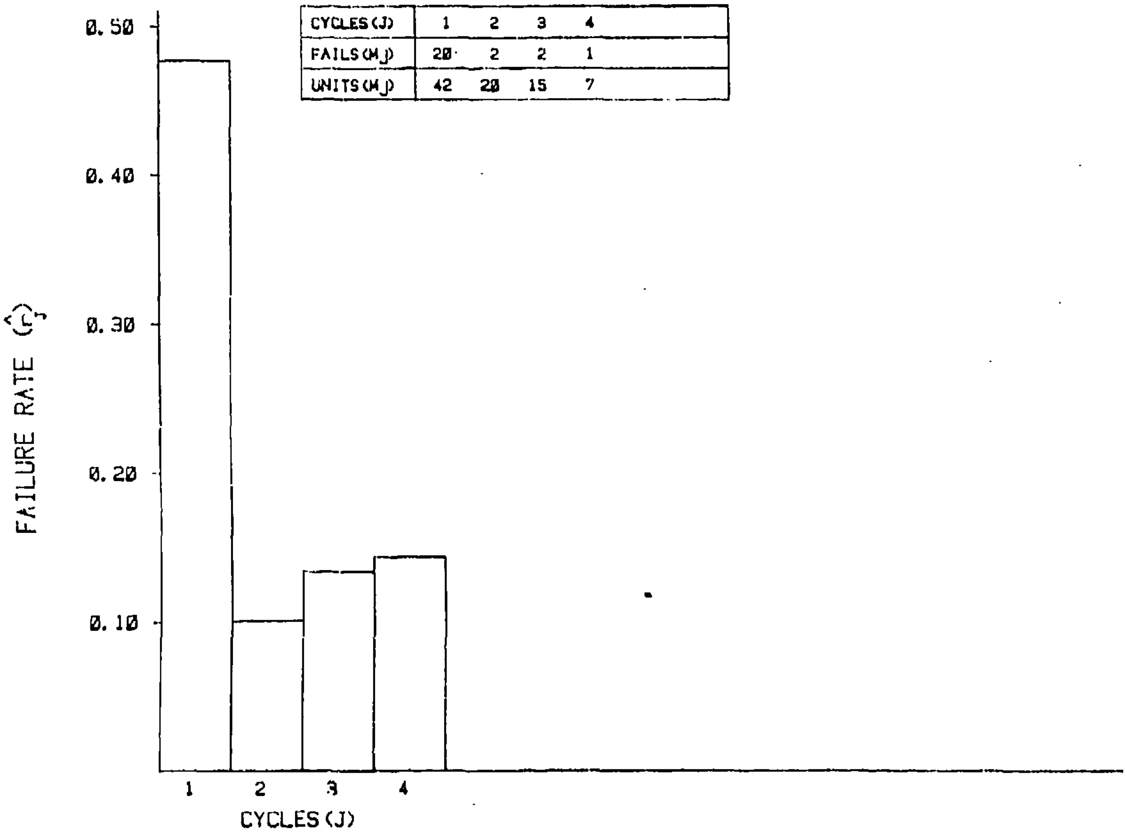


Figure 33. INS IMU Failure Rate for Third Failure (3 Cycle Burn-In)

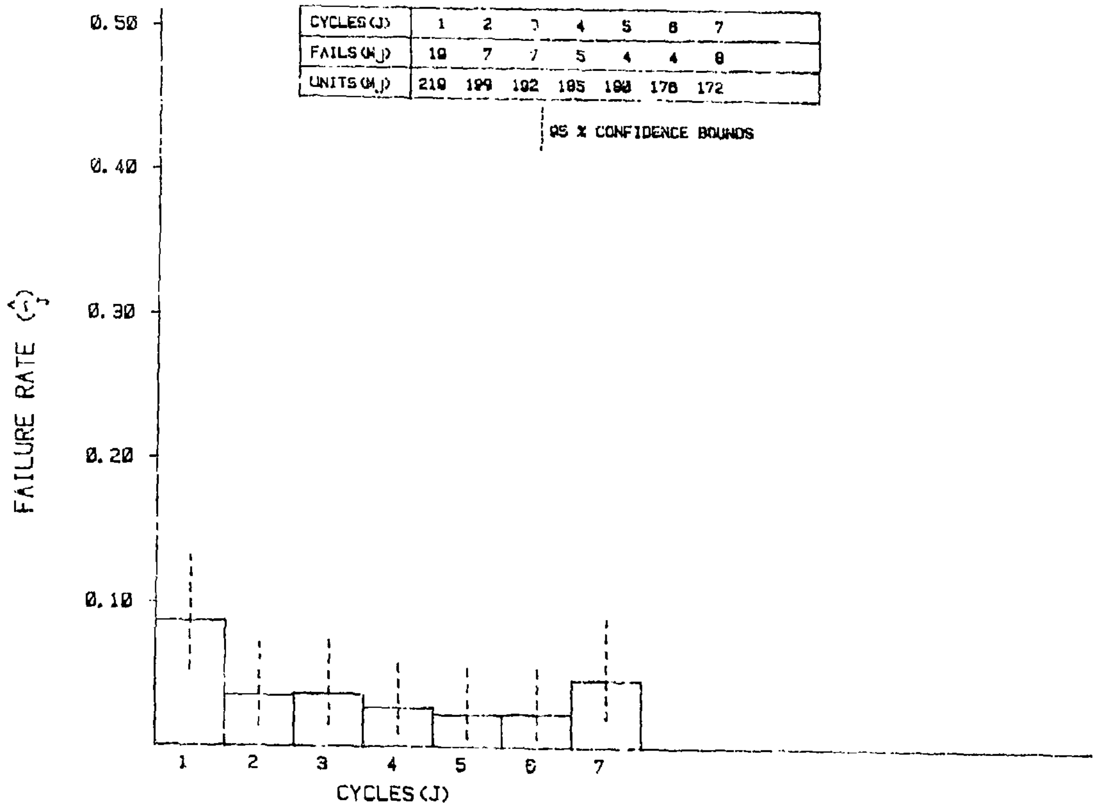


Figure 34. INS IMU Failure Rate for First Failure (7 Cycle Burn-in)

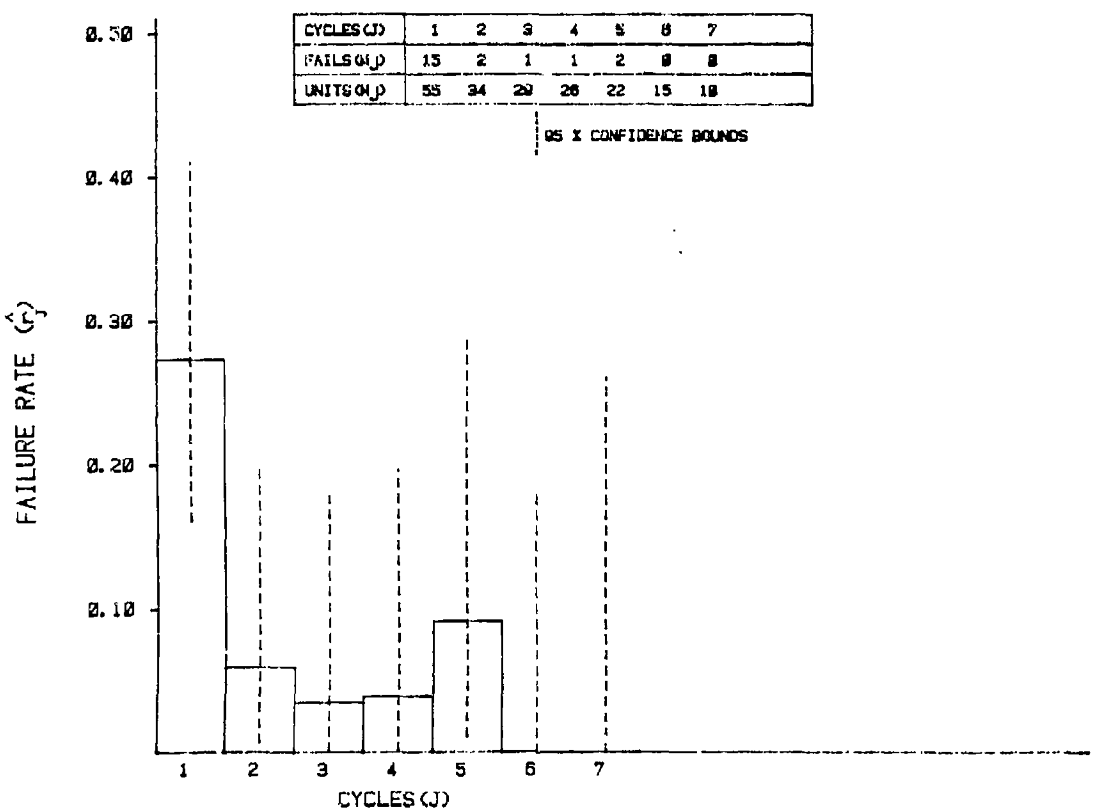


Figure 35. INS IMU Failure Rate for Second Failure (7 Cycle Burn-In)

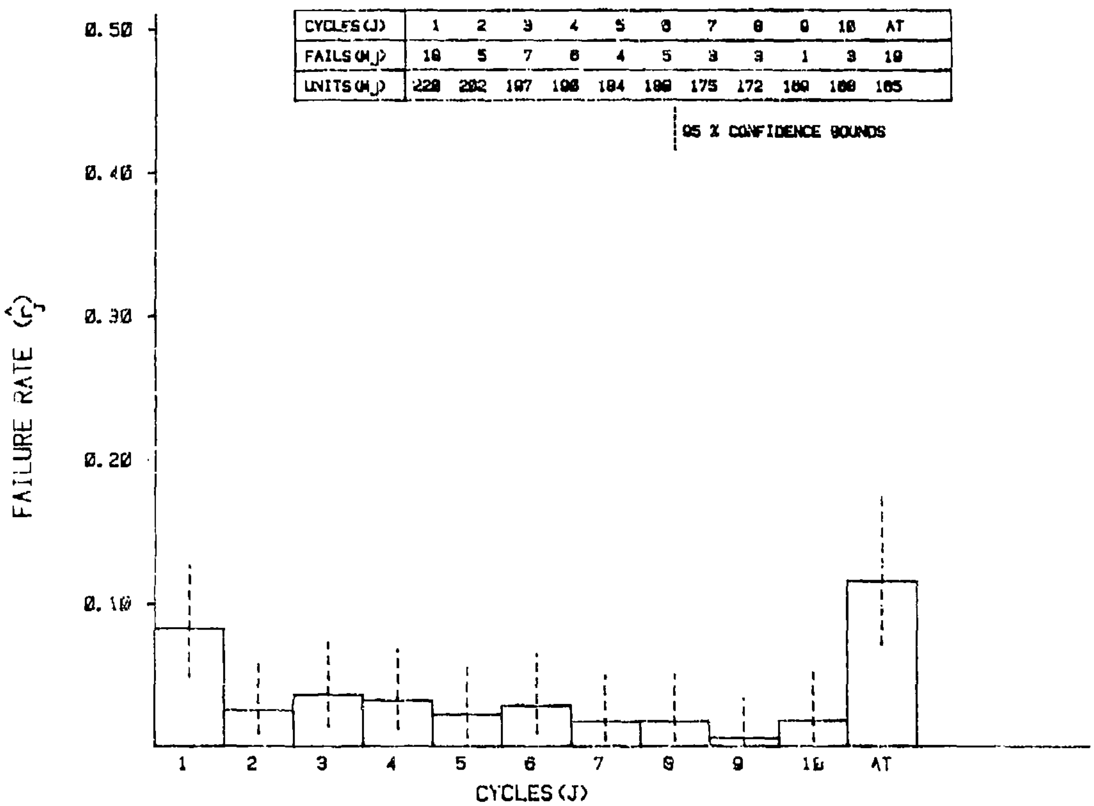
In Figures 36 and 37, the failure rates for the ten-cycle failure-free burn-in are provided. The failure rate for the IMU in the set acceptance test (AT) conducted on units which survive the ten cycles is also shown. Chi-Square tests for homogeneity reject the hypothesis of constant failure rate. The results are:

1st Failure $\chi^2(9) = 27.7 > \chi^2(9)(.05) = 16.9$

2nd Failure $\chi^2(9) = 22.9 > \chi^2(9)(.05) = 16.9$

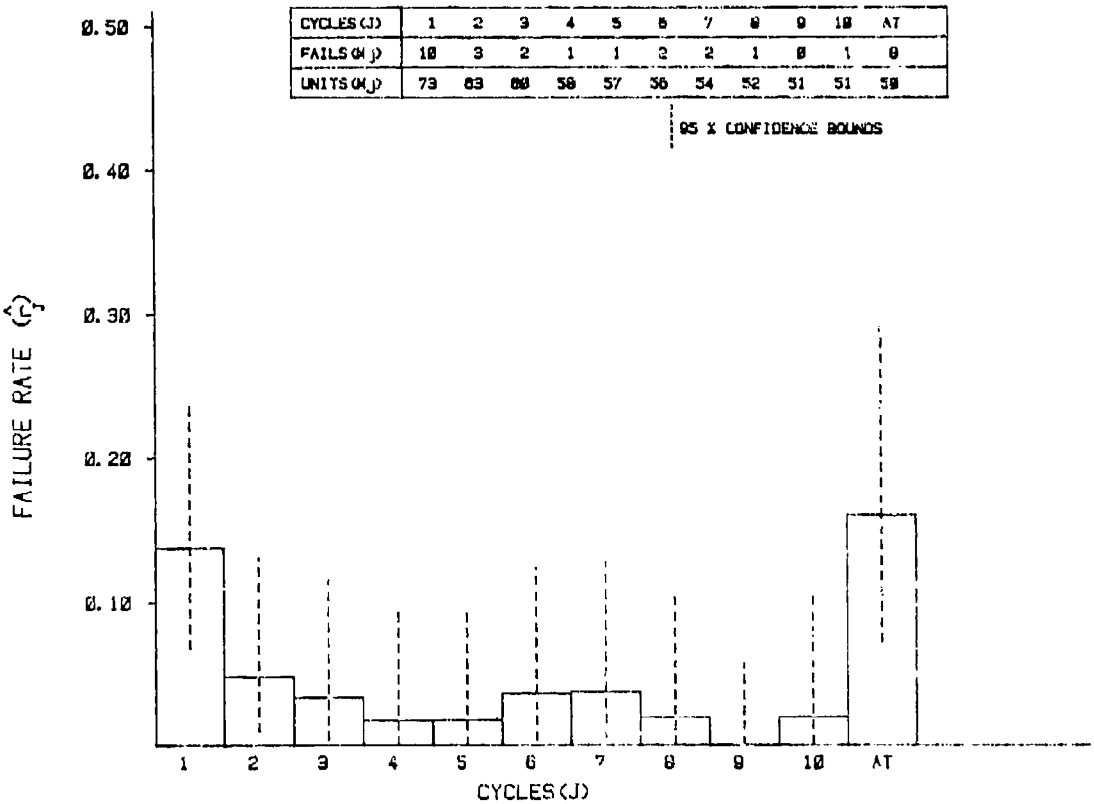
The failure rates follow the characteristic form shown in the previous burn-in tests: (1) decreasing failure rate in the first few cycles, (2) relatively constant failure rate subsequently, (3) reburn-in for failed units and (4) relatively large AT failure rate.

Comparing Figure 34 for the seven-cycle test with Figure 36 for the ten-cycle test, the failure rates are almost identical.



CYCLES (J)	1	2	3	4	5	6	7	8	9	10	AT
FAILS (H,J)	18	5	7	6	4	5	3	3	1	3	19
UNITS (H,J)	220	202	197	190	184	180	175	172	169	168	165

Figure 36. INS IMU Failure Rate for First Failure (10 Cycle Burn-In)



CYCLES (J)	1	2	3	4	5	6	7	8	9	10	AT
FAILS (H J)	10	3	2	1	1	2	2	1	0	1	0
UNITS (N J)	73	63	60	58	57	56	54	52	51	51	50

Figure 37. INS IMU Failure Rate for Second Failure (10 Cycle Burn-In)

One conclusion that might be drawn from this is that the seven-cycle burn-in does not significantly alter the reliability or distribution of time to failure of units which have completed the three-cycle burn-in. The relatively constant failure rate from cycle two and on in the three-cycle burn-in reenforces this conclusion. Given a constant failure rate at the end of the three-cycle burn-in, additional cycling would not be expected to provide significant reliability improvement. This appears to be the case.

d. <u>INS Navigation Control Indicator</u> - The failure rate for the INS Navigation Control Indicator (NCI) in the three burn-in tests are shown in Figures 38, 39 and 40. The small number of failures precludes meaningful analysis of the failure rates for second failure. The failure rate in the initial burn-in test (three-cycle) displays a significant decrease similar to that observed for the IMU. The failure rate becomes relatively constant after the first cycle.

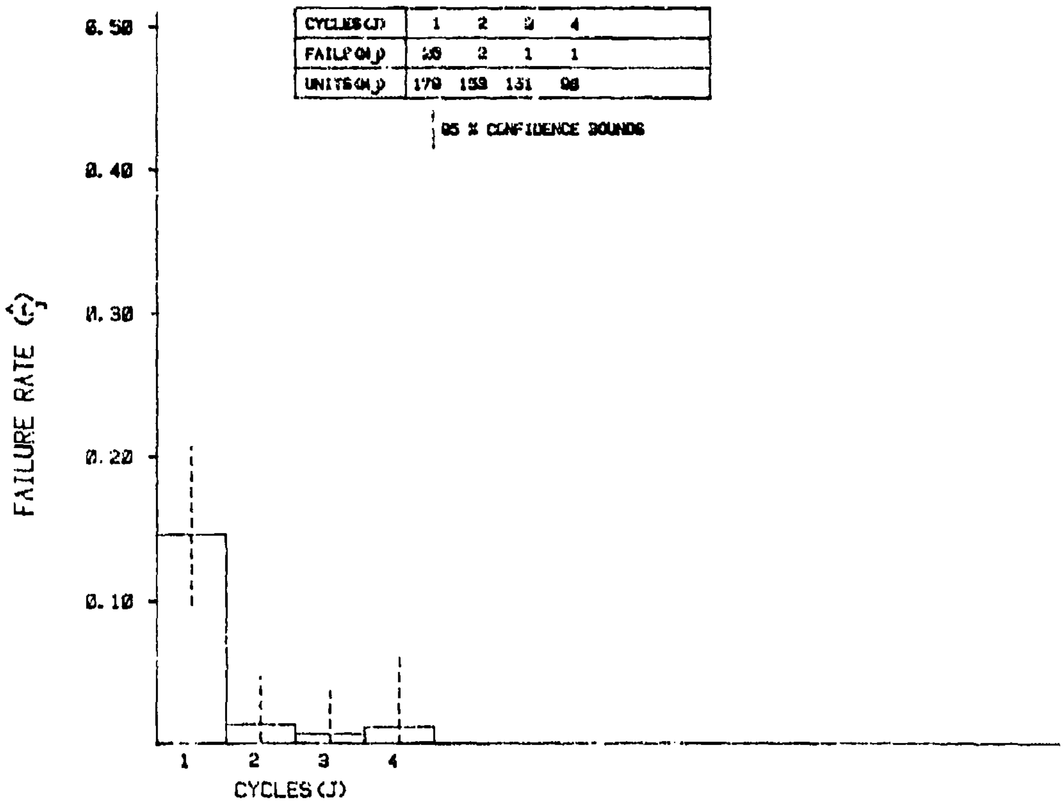


Figure 38. INS NCI Failure Rate for First Failure (3 Cycle Burn-in)

The failure rate for the seven-cycle burn-in (Figure 39) also appears to be decreasing. The Chi-Square test for homogeneity does not reject the hypothesis of constant failure rate for cycles 1-7 for $\alpha = .05$ ($\chi^2_{(6)} = 9.79 < \chi^2_{(6)}(.05) = 12.6$). However, if the failure rates for adjacent cycle pairs are pooled (1, 2, and 3, 4, and 5, 6), and tested for constant failure rate, the hypothesis is rejected for $\alpha = .05$ ($\chi^2_{(2)} = 7.07 > \chi^2_{(2)}(.05) = 5.99$). This indicates that the failure rate for the seven-cycle burn-in is also decreasing.

The failure rate for the ten-cycle burn-in is shown in Figure 40. The failure rate for the set AT is also shown. The burn-in failure rate appears to be decreasing. This is confirmed by the Chi-Square test ($\chi^2_{(9)} = 19.2 > \chi^2_{(9)}(.05) = 16.9$).

The AT failure rate is comparable to the failure rate during the burn-in, indicating that the performance tests are of comparable thoroughness.

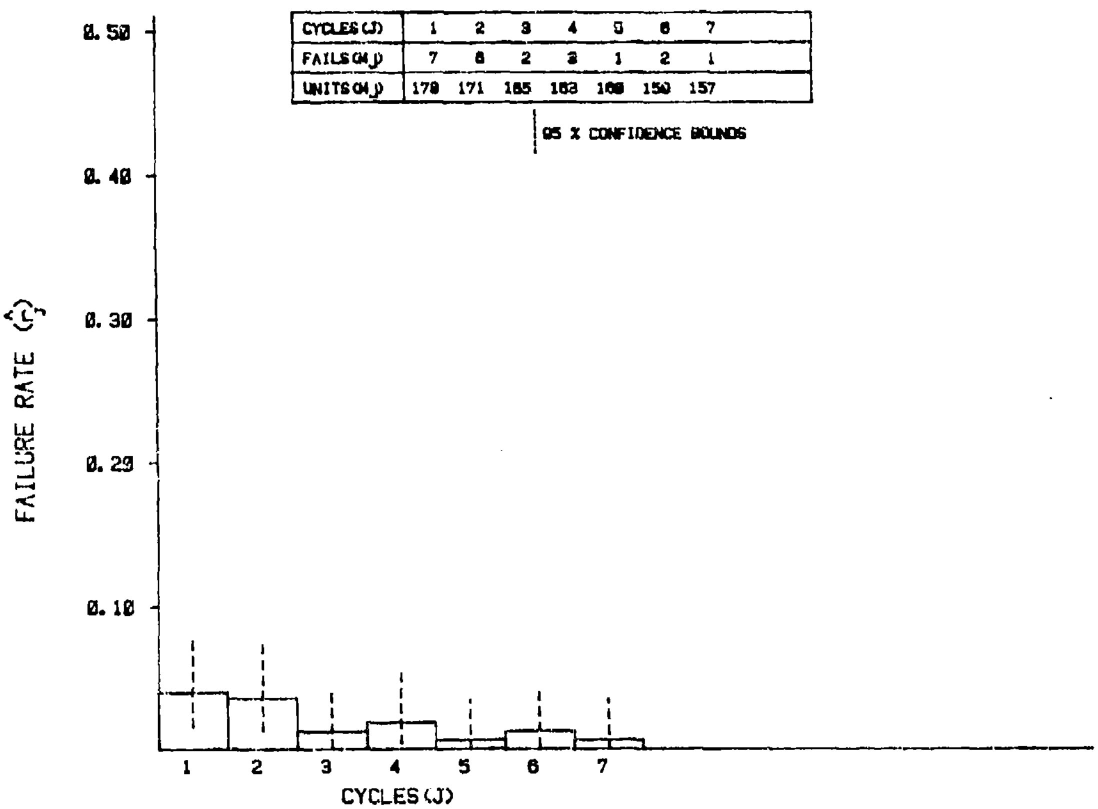


Figure 39. INS NCI Failure Rate for First Failure (7 Cycle Burn-In)

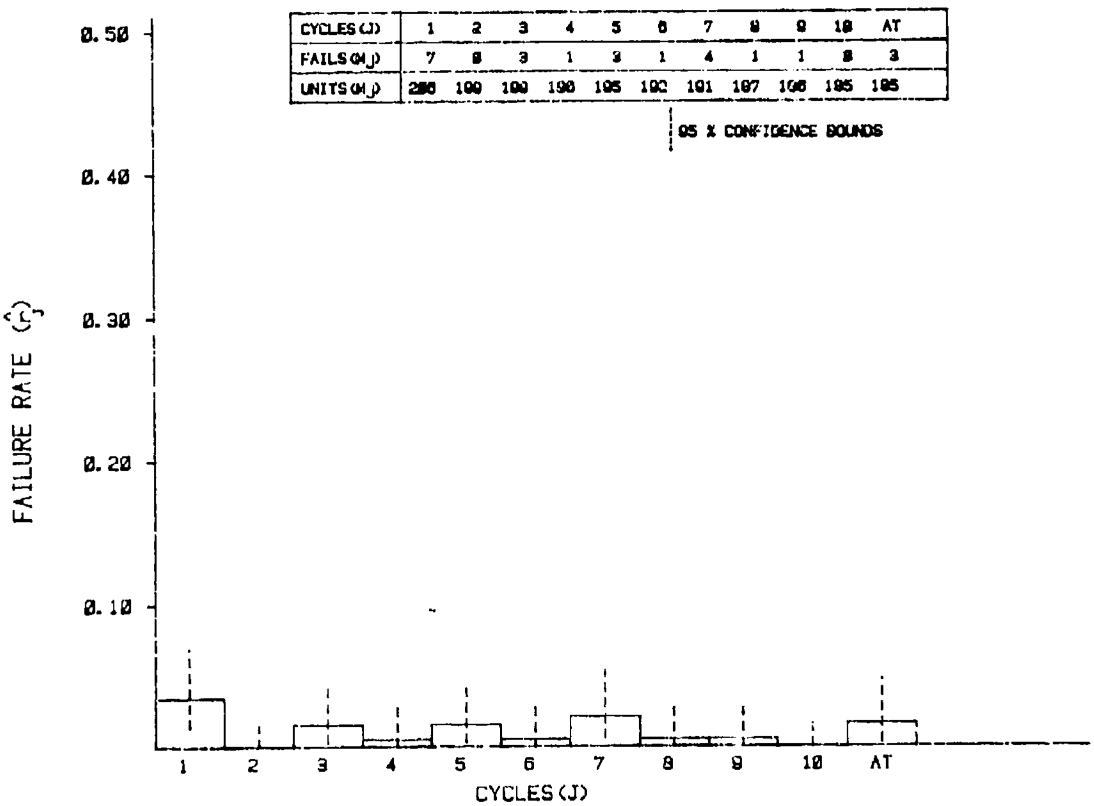


Figure 40. INS NCI Failure Rate for First Failure (10 Cycle Burn-In)

e. AFCS Roll/Yaw Computer - The burn-in for the AFCS Roll/yaw computer (RYC) consists of nine cycles of which the last three must be failure free. Figure 41 shows the resultant failure rate, based on the experience of 186 units. As shown in the figure, the failure rate is decreasing for the first three cycles and is relatively constant from cycles three to nine. The Chi-Square test rejects homogeneity for $\alpha = .05$ ($\chi^2_{(8)} = 33.5 > \chi^2_{(8)}(.05) = 15.5$). As with previous systems, the failure rate becomes constant after one or two cycles of burn-in. Results of the AT were not available.

f. AFCS Pitch Computer - The AFCS pitch computer (PC) burn-in test is identical to that of the RYC. The failure rate for first failure is shown in Figure 42. From the figure, it appears that the failure rate is decreasing slightly or constant in the burn-in test. The Chi-Square test (for Cycles 1-9) does not

reject the homogeneity hypothesis for $\alpha = .05$ ($\chi^2_{(8)} = 14.1 < \chi^2_{(8)}(.05) = 15.5$). The Chi-Square test applied to adjacent pairs (1, 2: 3, 4: etc.) also does not reject ($\chi^2_{(3)} = 6.65 < \chi^2_{(3)}(.05) = 7.81$).

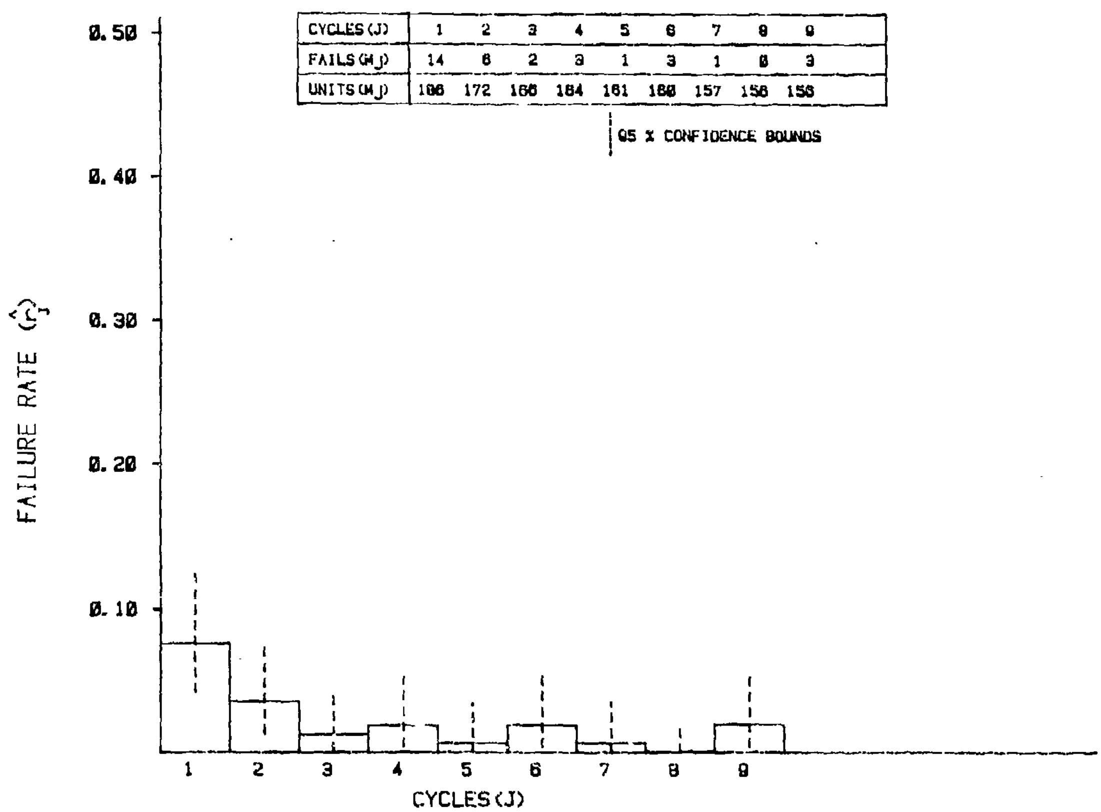


Figure 41. AFCS Roll/Yaw Computer Failure Rate for First Failure (9 Cycle Burn-In)

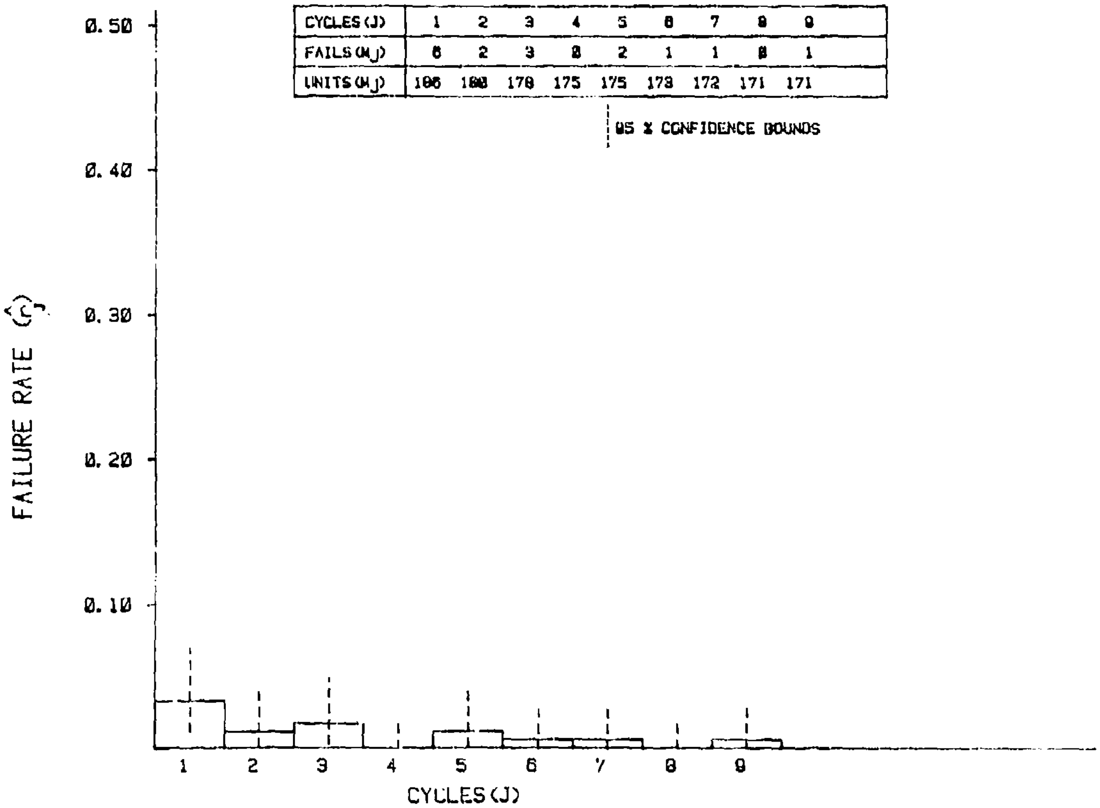


Figure 42. AFCS Pitch Computer Failure Rate for First Failure (9 Cycle Burn-In)

g. <u>AFCS Accelerometer Sensor and Rate Gyro</u> - As described in Section II, the accelerometer and rate gyro burn-in consists of six temperature cycles with a functional test at ambient temperature after the third and sixth cycles. The failure rate for both units is shown in Figure 43. Failures in the post third and sixth cycle ambient test were counted as failing in cycles 3 and 6 respectively. As shown in the figure, during the six-cycle test, the performance test is not the same for all cycles. Also, the acceptable tolerances for the tests are narrowed after cycle three.

The combination of test differences, tolerance changes and unit aging explains the erratic form of the failure rate. The failure rate decreases from cycle 1 to 2 as defective units are removed. In cycle 3, the failure rate increases slightly, due to aging and inclusion of the ambient performance test failures. The failure rate increases again in cycle 4 due to the tightened tolerances of the performance test. The failure rate decreases in Cycle 5 due to removal of defectives and a less stringent performance test (null only). The failure rate then increases in the last cycle, due to a more thorough performance test and inclusion of the ambient test results.

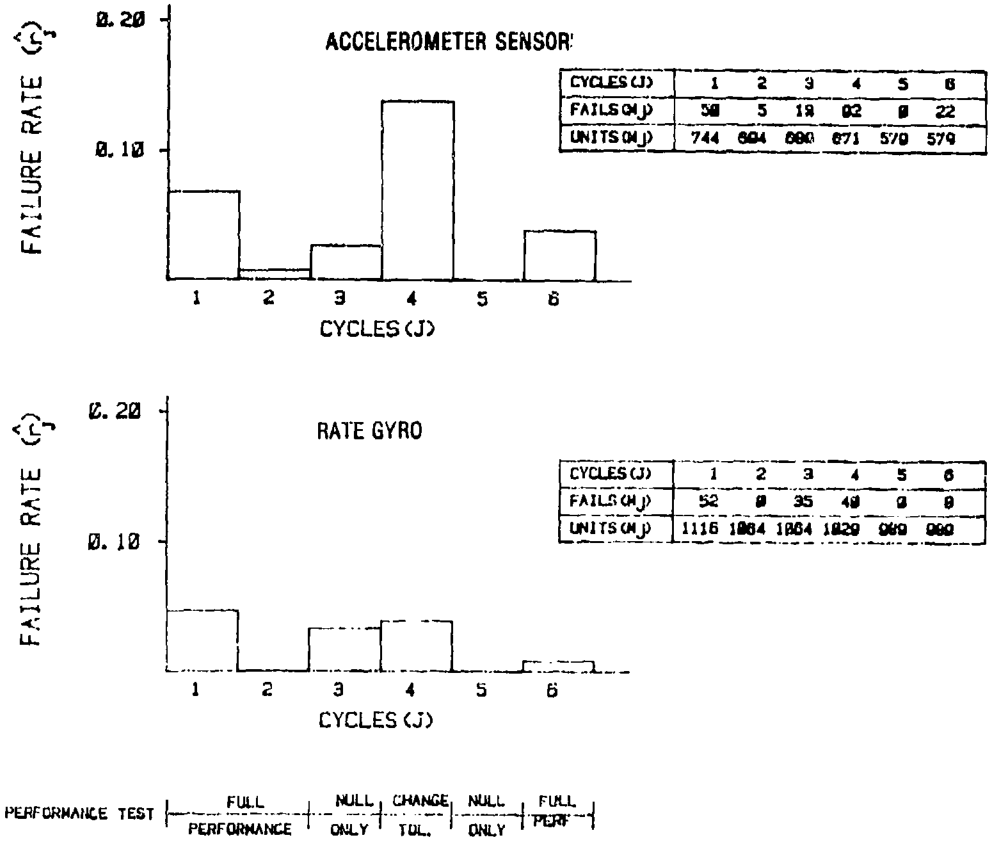


Figure 43. AFCS Accelerometer and Rate Gyro Failure Rate in Burn-In (First Failure)

The test is conducted primarily to harmonize the unit mechanical properties and detect changing performance with temperature. The number of units listed in Figure 43 is approximate. An exact count was not available.

h. AFCS Engaging Controller - The AFCS Engaging Controller (EC) burn-in consists of two consecutive temperature cycles required to be failure free. The EC failure rate based on 186 units is shown in Figure 44. The failure rate is constant for the two cycle test indicating that there is no discernable reliability improvement as a result of the burn-in process.

i. AFCS Stick Force Sensor - The AFCS Stick Force Sensor (SFS) burn-in is also a two-cycle failure-free test. The failure rate estimates based on the results of 186 units are shown in Figure 45. As shown in the figure, the failure rate estimates are decreasing with cycle. The Chi-Square test, however, does not reject the constant failure rate hypothesis ($X^2_{(1)} = 2.14 < X^2_{(1)(.05)} = 3.84$).

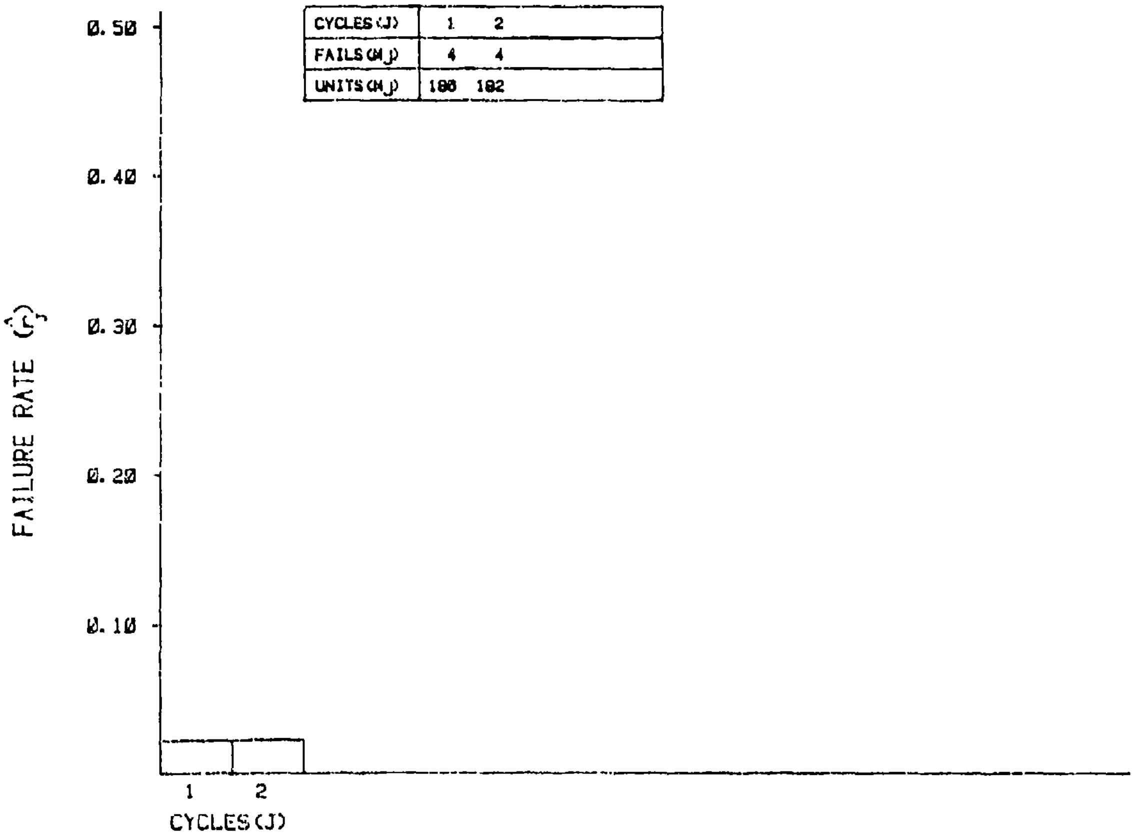


Figure 44. AFCS Engaging Controller Failure Rate (First Failure)

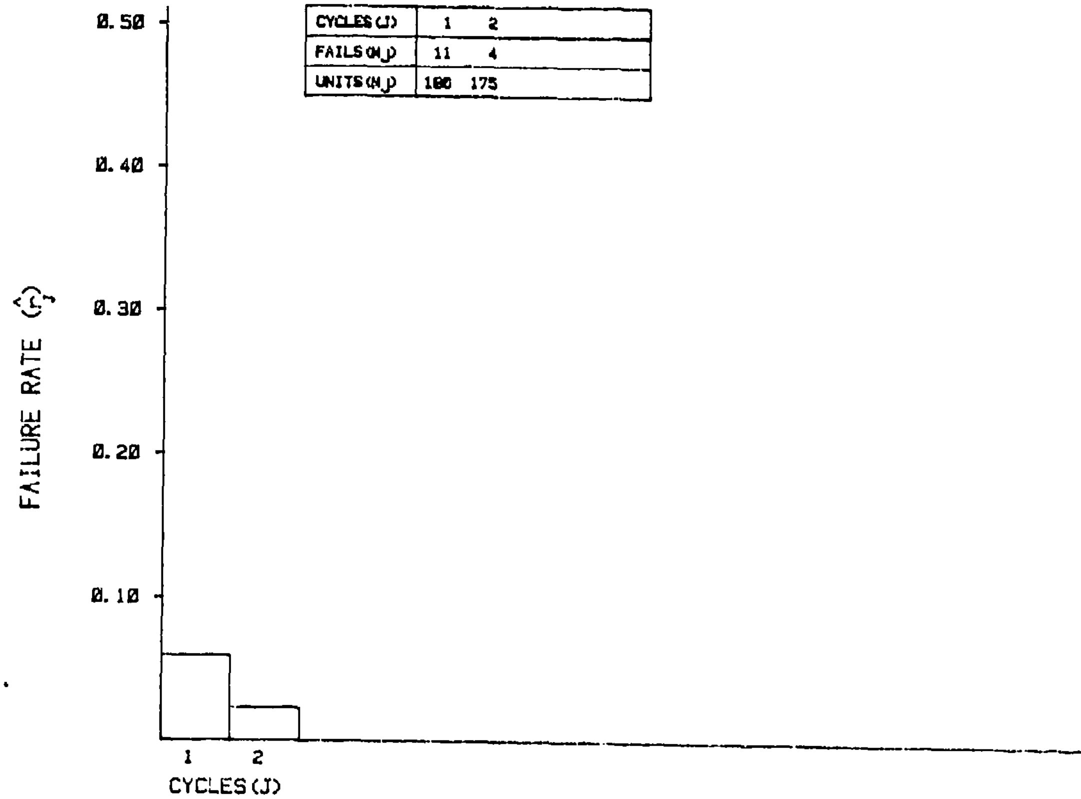


Figure 45. AFCS Stick Force Sensor Failure Rate (First Failure)

j. Inertial Navigation Unit - The Inertial Navigation Unit (INU) burn-in contains three temperature cycles, the last two of which must be consecutively failure free. The results of the burn-in of 184 units is shown in Figures 46-48 for the first, second, and third failure. Figure 46 shows a decreasing failure rate for first failure of the production units. The Chi-Square test rejects homogeneity for cycles 1 through 3 (α = .05). It also rejects homogeneity of Cycles 1 versus 2 and 1 versus 3 but does not reject 2 versus 3. Based on the Chi-Square test and the point estimates, the failure rate decreases from cycles one through three.

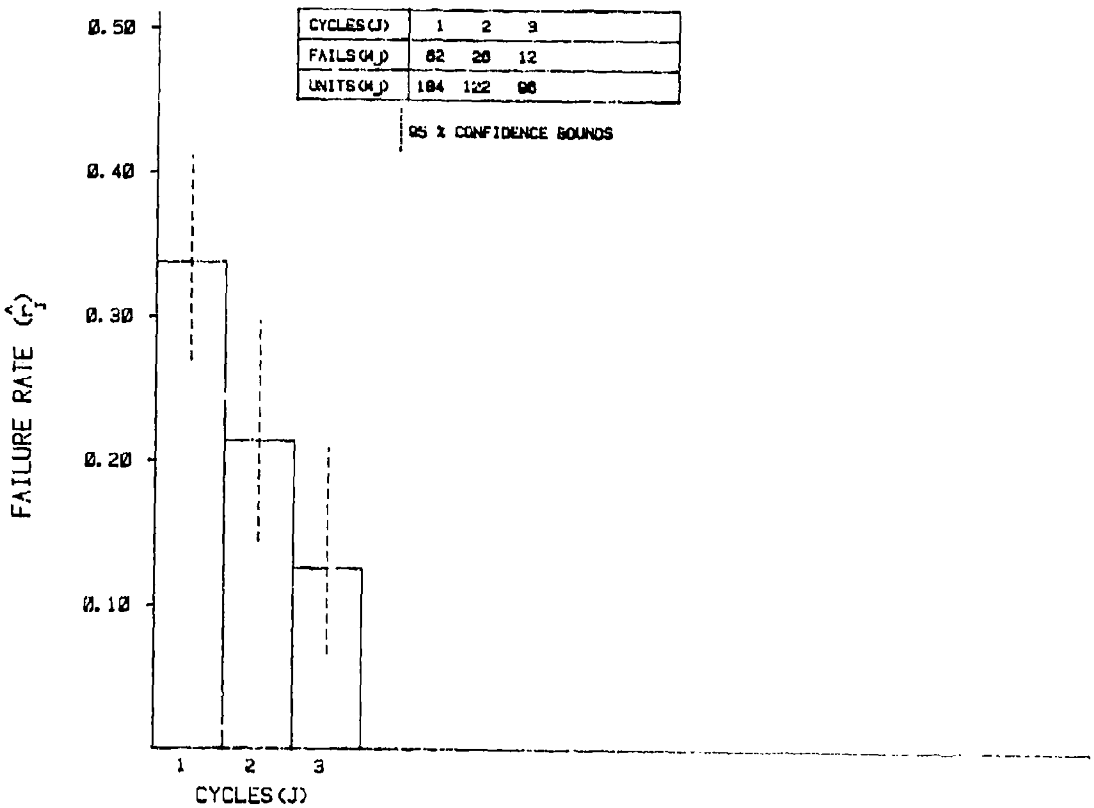


Figure 46. INU Failure Rate for First Failure in Burn-In

Figure 47 shows the failure rate for second failure. As with the previous systems (HUD, INS) the reburn-in phenomenon is present, as evidenced by the decreasing failure rate for second failure. The Chi-Square test rejects constant failure rate (α = .05). Figure 48 also shows the reburn-in for units which have failed twice. The hypothesis of constant failure rate for cycles 1 through 3 is not rejected in the Chi-Square test, however. After completing the three-cycle burn-in, 20.6% of the units fail a functional performance test conducted at room ambient temperature.

k. FGS Pitch Computer - The FGS pitch computer burn-in consists of sixteen temperature cycles followed by the unit acceptance test. As described in Section III, the performance test of the unit during burn-in is conducted once every four cycles. Because of this, the failure data is grouped into four-cycle intervals.

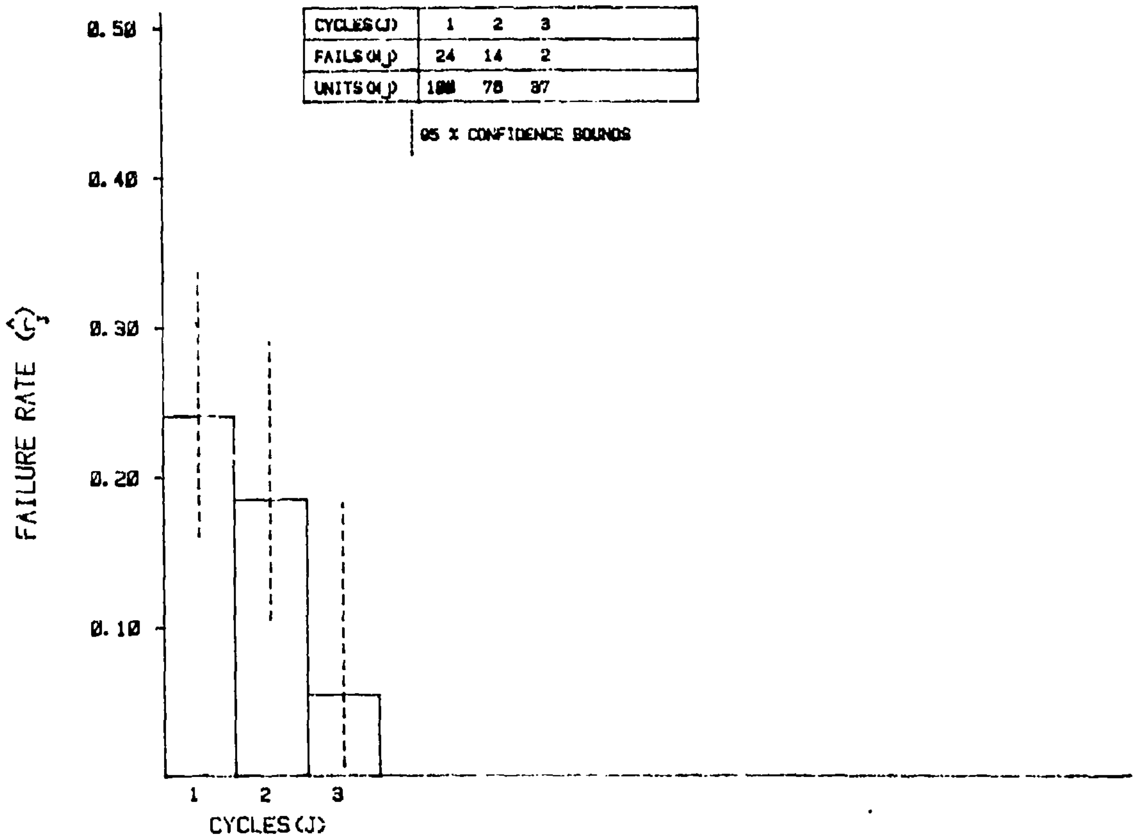


Figure 47. INU Failure Rate for Second Failure In Burn-In

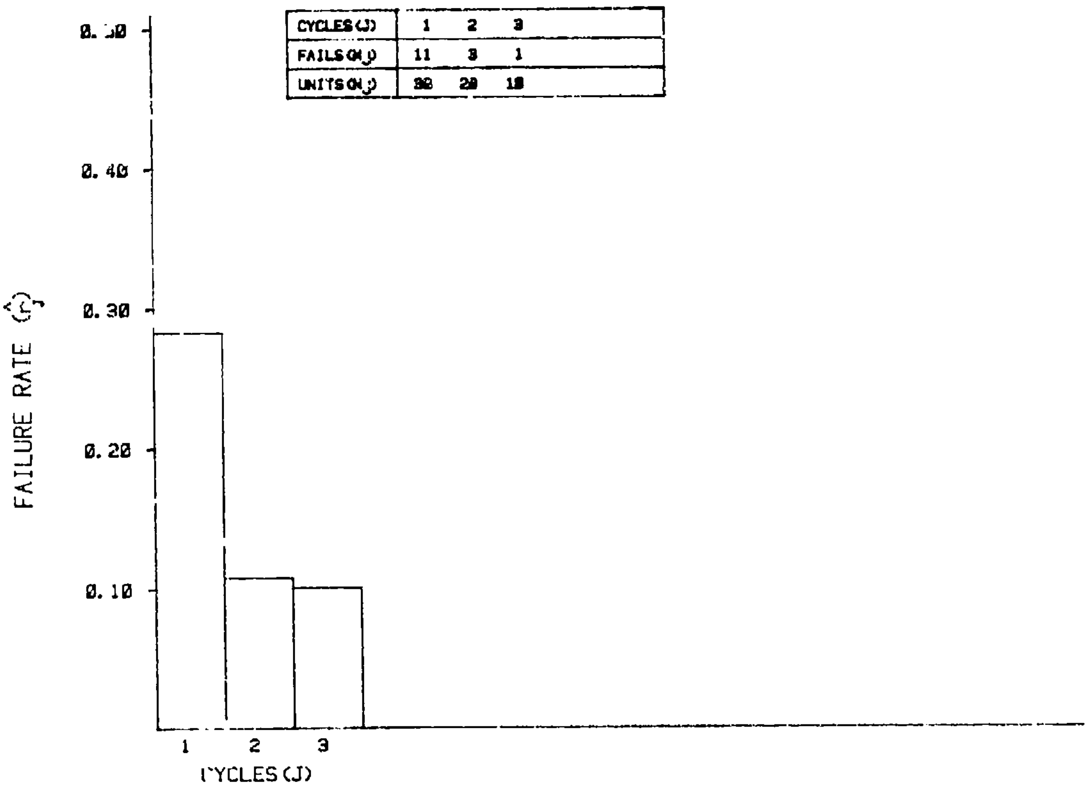


Figure 48. INU Failure Rate for Third Failure in Burn-In

Figure 49 shows the failure rate for the pitch computer. The failure rate for the AT is also shown. As with tests described previously, the relatively high AT failure rate (0.91) is indicative of the disparity between the AT and the functional performance test conducted during burn-in. The Chi-Square test for homogenity for the four pooled intervals of Figure 49 does not reject a hypothesis of constant failure rate. However, if the pooled result for the first eight cycles (1-8) is compared to the last eight (9-16), homogeneity is rejected ($\chi^2_{(1)} = 4.05 > \chi^2_{(1)}(.05) = 3.84$). This result, in conjunction with the point estimates, indicates a decreasing failure rate for the pitch computer.

Unfortunately, the test frequency (once every four cycles) precludes direct comparison with failure rate behavior of other equipments analyzed in this report. The failure rate does appear to decrease less rapidly than the previous equipments analyzed (HUD, INS, etc.).

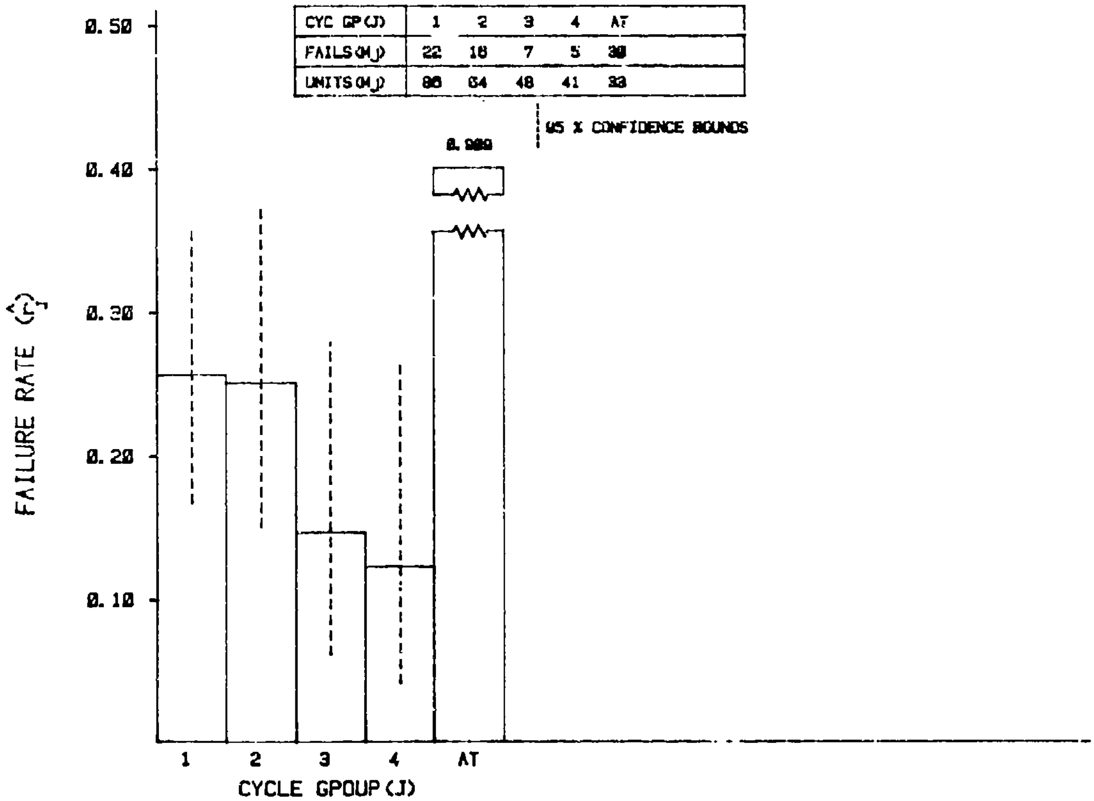


Figure 49. FGS Pitch Computer Failure Rate (First Failure)

Figure 50 is the pitch computer failure rate for second failure, again pooled in four-cycle intervals. The failure rate appears to decrease faster than the failure rate for first failure and is similar to that observed on previous equipments (INS, HUD, etc.). The initial failure rate (Cycles 1-4) is relatively high indicating the presence of the reburn-in process. The Chi-Square test does not reject homogeneity at $\alpha = .05$ ($\chi^2_2 = 4.93 < \chi^2_{(2)(.05)} = 5.99$).

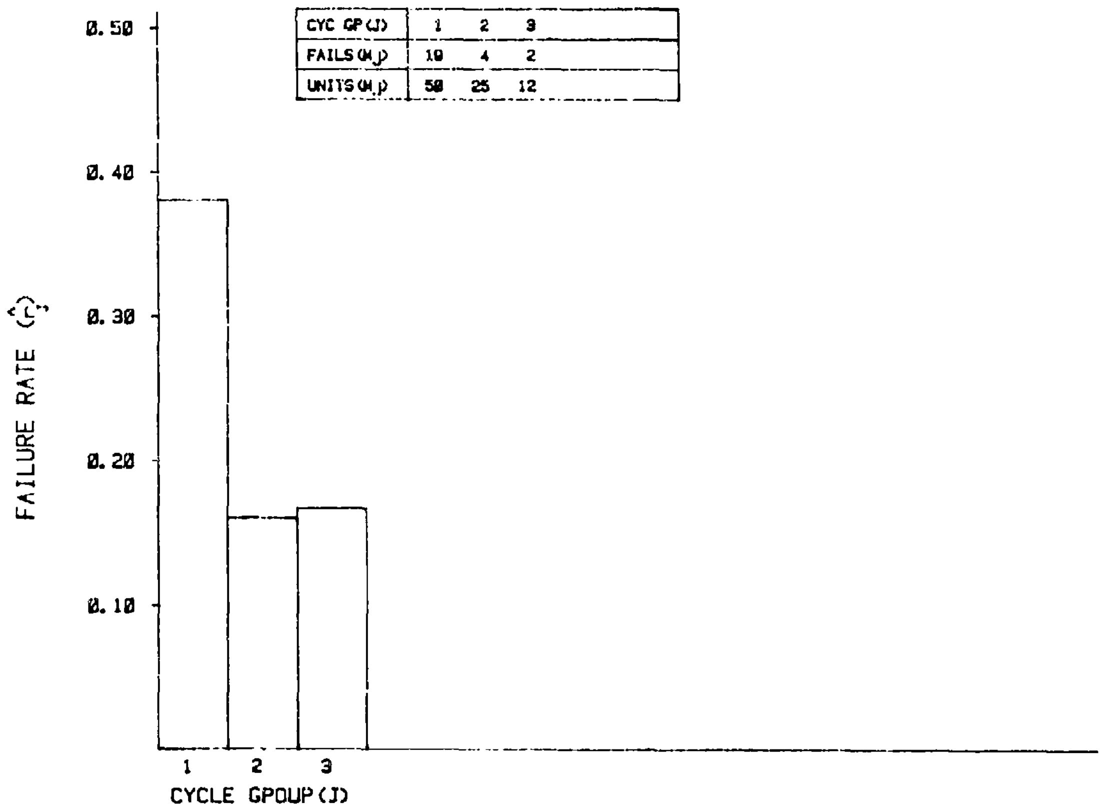


Figure 50. FGS Pitch Computer Failure Rate (Second Failure)

1. FGS Roll Computer - The FGS roll computer burn-in failure rate is shown in Figures 51 and 52 for the first and second failures. As done for the pitch computer, the results are pooled in four cycle intervals due to the test frequency. The failure rate for first failure decreases after eight cycles and resembles the form for the pitch computer. The Chi-Square test for homogeneity of the failure rate for the first eight cycles versus the last eight rejects for $\alpha = .05$ ($\chi^2_{(1)} = 6.22 > \chi^2_{(1)(.05)} = 3.84$) indicating a decreasing failure rate.

As observed for the pitch computer, the roll computer AT failure rate is also relatively large indicating a performance test disparity for this unit also.

Unlike the pitch computer, the roll computer failure rate for second failure (Figure 52) is relatively constant over the intervals shown. Although the reburn-in characteristic may be present it is not discernible in the pooled data.

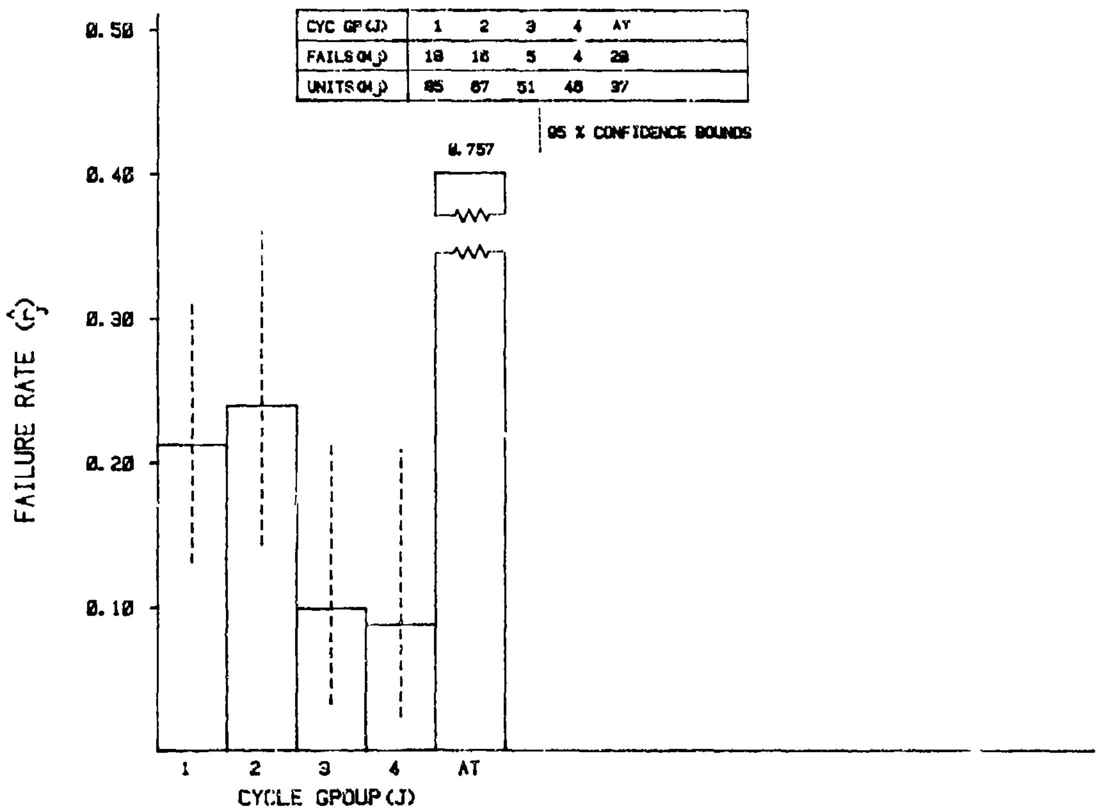


Figure 51. FGS Roll Computer Failure Rate (First Failure)

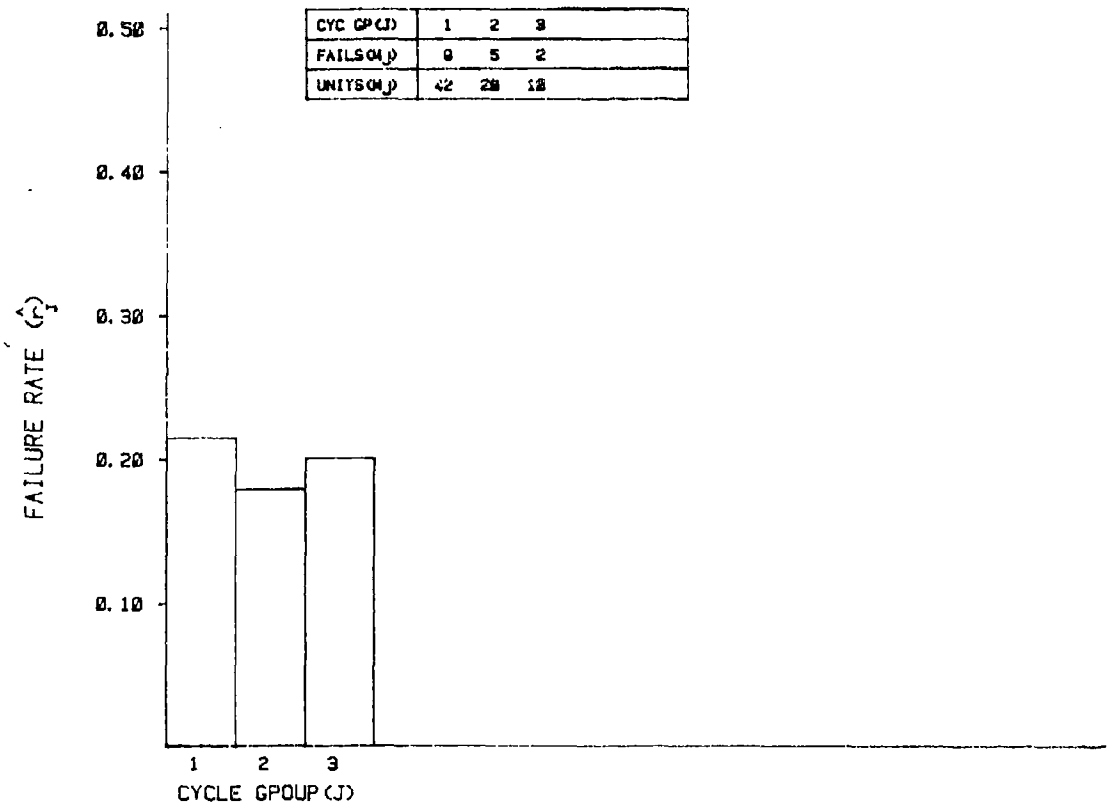


Figure 52. FGS Roll Computer Failure Rate (Second Failure)

m. FGS Yaw Computer - The FGS yaw computer failure rates for burn-in are shown in Figures 53 and 54. The point estimates for the failure rate for first failure are decreasing in the burn-in. The Chi-Square test, however, does not reject homogeneity for = .05. As with the other FGS computers, the AT failure rate is relatively large. The failure rate for second failure (Figure 54) is relatively constant and does not appear to display the reburn-in characteristic. This may be masked by the pooling effect noted previously and the small sample size.

n. Digital Air Data Computer - The Digital Air Data Computer (DADC) failure rates for the burn-in are shown in Figures 55 and 56. The failure data for the DADC was provided in terms of equipment power-on time, grouped in 25 hour increments as opposed to the cycle of failure used in the previous analysis.

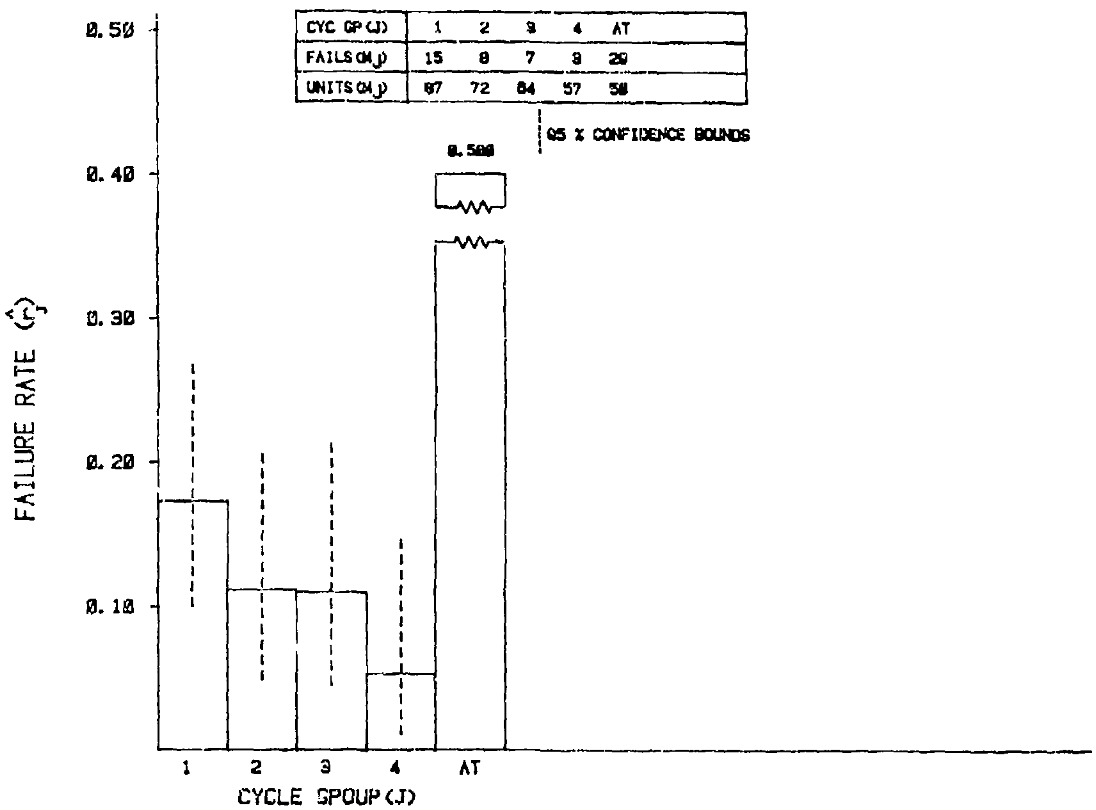


Figure 53. FGS Yaw Computer Failure Rate (First Failure)

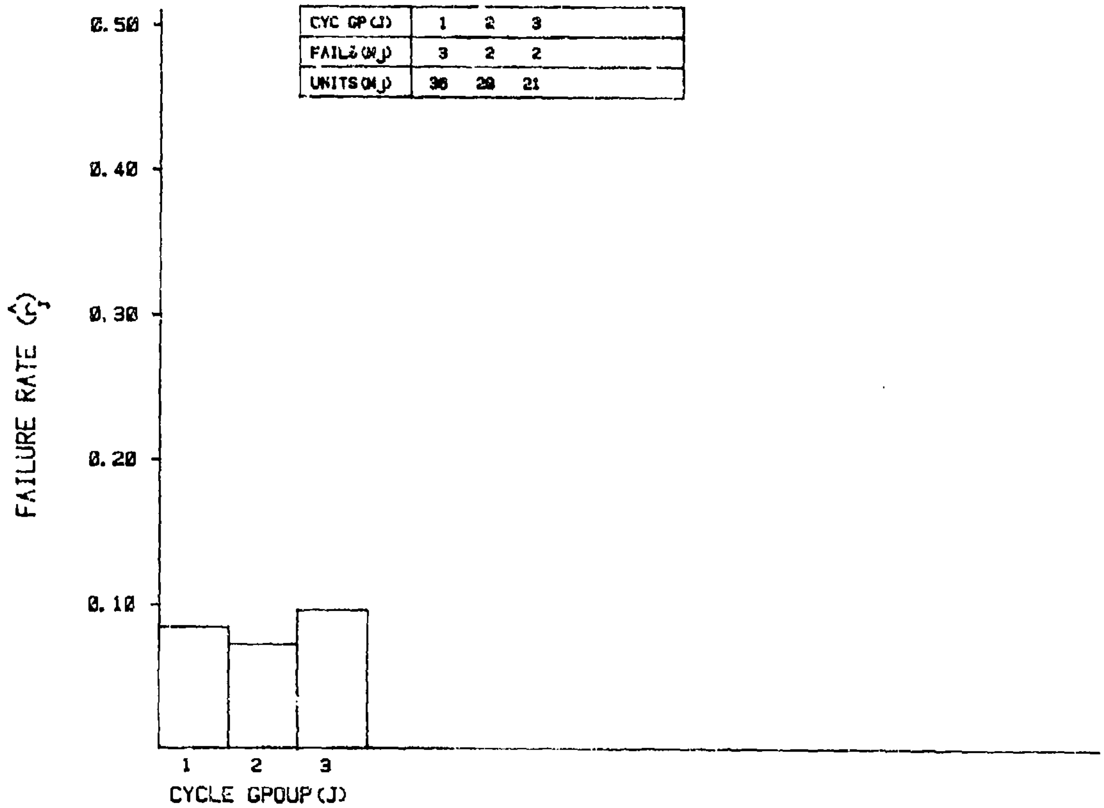


Figure 54. FGS Yaw Computer Failure Rate (Second Failure)

The failure rate for first failure is shown in Figure 55. The failure rate initially decreases (0-75), reaches steady state (75-175), and appears to increase in the last interval. The equipment manufacturer was contacted to determine if the increase could be due to changes in test procedures, equipment flow or data collection anomalies. No anomalies were found which would explain the behavior.

The Chi-Square test rejects homogeneity for intervals 1 through 8 and 2 through 8 ($X^2_{(7)} = 61.7 > X^2_{(7)(.05)} = 14.1$, $X^2_{(6)} = 17.27 > X^2_{(6)(.05)} = 12.6$). The test for homogeneity for intervals 3 through 8 does not reject, however, ($X^2_{(5)} = 8.04 < X^2_{(5)(.05)} = 11.1$). In the absence of evidence to the contrary, the increasing point estimates in the last intervals are considered to be sampling noise and the failure rate is classified as decreasing.

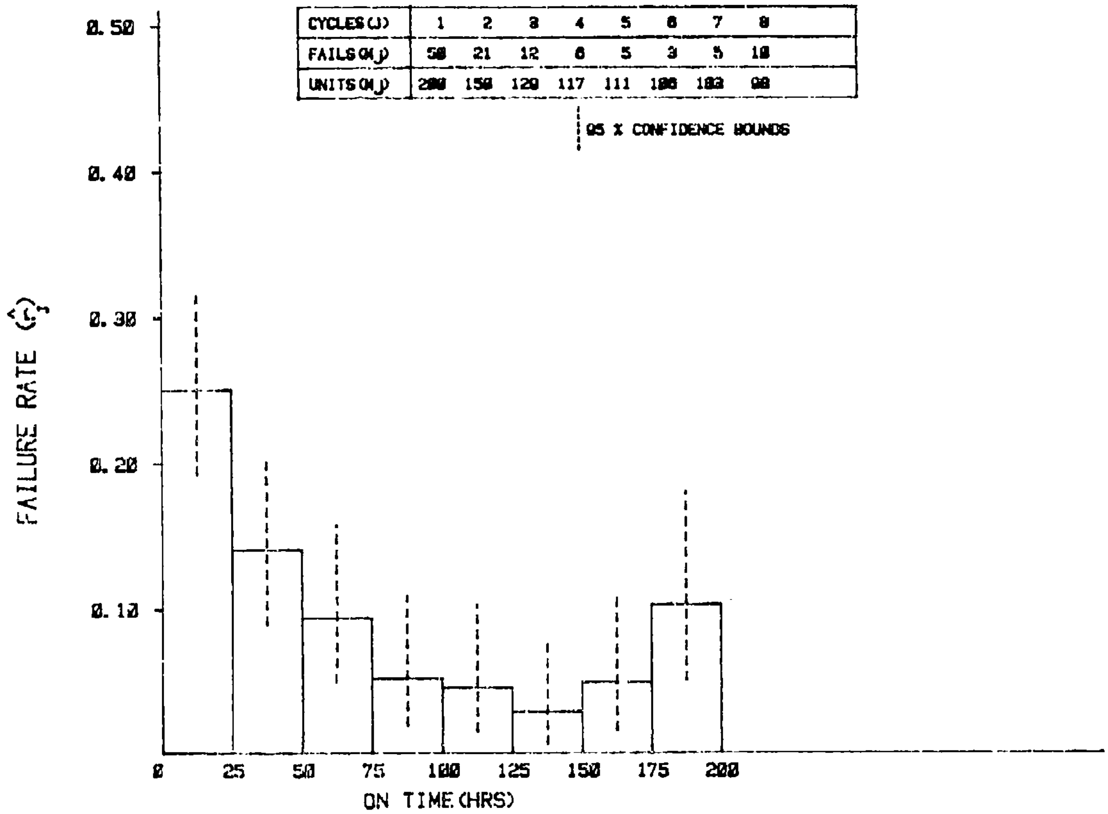
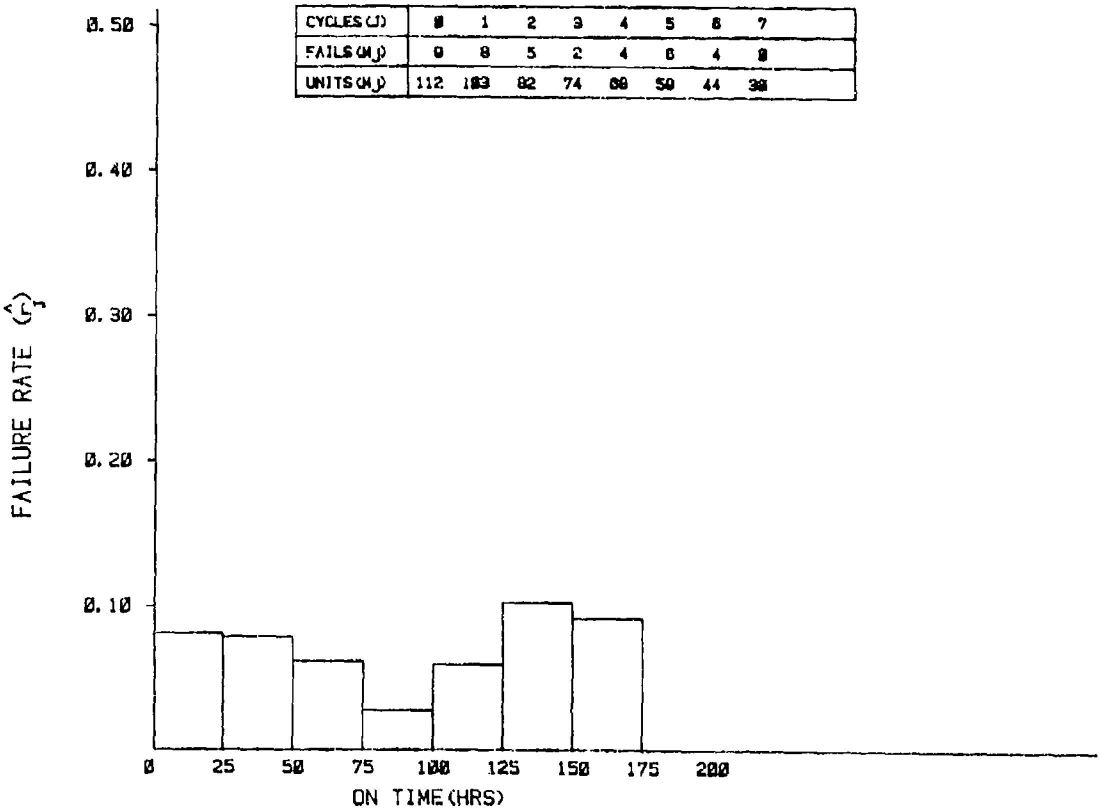


Figure 55. DADC Failure Rate (First Failure)

Figure 56 is the DADC failure rate for second failure. As seen in the figure, the failure rate is relatively constant throughout the burn-in for units which have failed once. The reburn-in characteristic behavior is not in evidence. Since many of the other equipments had shown this characteristic, the equipment manufacturer was contacted. The manufacturer said that repeat failures which occurred shortly (* 25 hrs) after repair were not included in the failure data. This would explain the absence of the reburn-in characteristic.



CYCLES (J)	0	1	2	3	4	5	6	7
FAILS (M_j)	9	8	5	2	4	6	4	0
UNITS (M_j)	112	103	82	74	68	59	44	30

Figure 56. DADC Failure Rate (Second Failure)

2. ESTIMATION OF MODEL PARAMETERS

The parameters (a_0, a_1, a_2) of the reliability model (Equation A-4) for equipment during burn-in were estimated using the maximum likelihood technique described in Appendix A. The MLE were obtained by solving Equation A-13 for the values of a_0, a_1, a_2 which maximized the likelihood function. The values of m_j and M_j are those shown for the discrete failure rates in the previous section. The time (t_j) is the equipment power-on time for each cycle. Solutions of the likelihood equation were obtained using a constrained optimization computer program previously developed at MCAIR.

The MLE for the parameters are shown in Table 11 for each equipment, burn-in test and failure number. $\Delta t = t_j - t_{j-1}$ the equipment power-on time for each cycle or interval is also listed.

TABLE 11. MLE FOR THE MODEL PARAMETERS

Equipment	Test (cycles)	Fail Number	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$	Δt
HUD DU	12	1	0.0123	0.1205	0.3942	4.00
		2	0.0125	0.0766	0.3628	
	8	1	0.0046	0.0504	7.7543	4.00
		2	0.0043	0.0443	7.5976	
HUD SDP	12	1	0.0032	0.1542	0.1485	4.00
		2	0.0041	0.0980	0.2189	
	8	1	0.0046	0.1447	0.2305	4.00
		2	0.0062	0.0470	0.4428	
INS IMU	3	1	0.0143	0.3736	1.6334	2.25
		2	0.0185	0.3398	14.1246	
		3	0.0529	0.3571	14.1994	
	7	1	0.0136	0.0623	1.0241	2.25
		2	0.0174	0.2541	1.1234	
	10	1	0.0073	0.1176	0.2790	2.25
		2	0.0095	0.1532	0.6201	
INS NCI	3	1	0.0037	0.1417	1.5082	2.25
	7	1	0.0025	0.0944	0.2156	2.25
	10	1	0.0036	0.0259	15.3413	2.25
AFCS Roll/Yaw Computer	9	1	0.0021	0.0976	0.2228	5.00
AFCS Pitch Computer	9	1	0.0009	0.0494	0.1462	5.00
INU	3	1	0	0.8797	0.1215	4.00
		2	0	0.6220	0.1305	
		3	0.0249	0.1901	0.7999	
FGS Pitch Computer	16	1	0	1.2217	0.0157	16.00
		2	0.0101	0.2178	1.8935	
FGS Roll Computer	16	1	0	0.9010	0.0193	16.00
		2	0.0115	0.0301	1.7615	
FGS Yaw Computer	16	1	0	0.6076	0.0207	16.00
		2	0.0051	0	0.1415	
DADC	21	1	0.0021	0.3296	0.0378	25.00
		2	0.0024	0.0360	0.0405	

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A visual representation of how well the failure rate of the burn-in model (Equation A-5) characterizes the observed failure rate may be obtained by plotting the estimate of the average failure rate ($\hat{\bar{\lambda}}_j$) per cycle (j) and the model failure rate ($\hat{\lambda}(t)$) using the estimated parameters ($\hat{a}_0$, $\hat{a}_1$, $\hat{a}_2$). From Appendix A, the two failure rates are:

$$\hat{\lambda}(t) = \hat{a}_0 + \hat{a}_1 \hat{a}_2 e^{-\hat{a}_2 t}, \ t > 0$$

$$\hat{\bar{\lambda}}_j = \frac{m_j}{M_j \Delta t}, \ j = 1, 2, \ldots, K$$

The values of m_j and M_j are obtained from the results of the previous section. Δt is provided in Table 11, as are the parameter estimates $\hat{a}_0$, $\hat{a}_1$, $\hat{a}_2$. Examples obtained in this fashion are shown in Figures 57-61. Figures 57 and 58 show the comparison of the average failure rate with the model, where the failure rate initially decreases and becomes constant. Figure 59 shows the flexibility of the model in describing rapidly decreasing failure rates followed by a relatively constant failure rate.

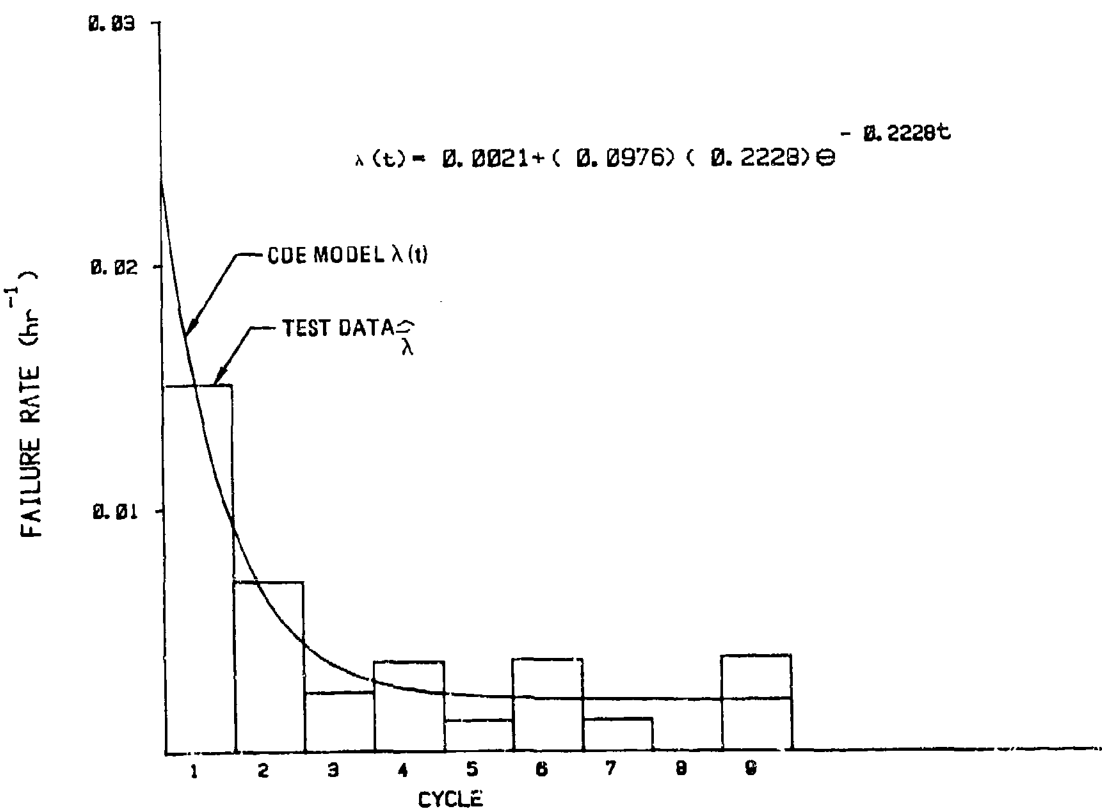

Figure 57. AFCS Roll/Yaw Computer Failure Rates

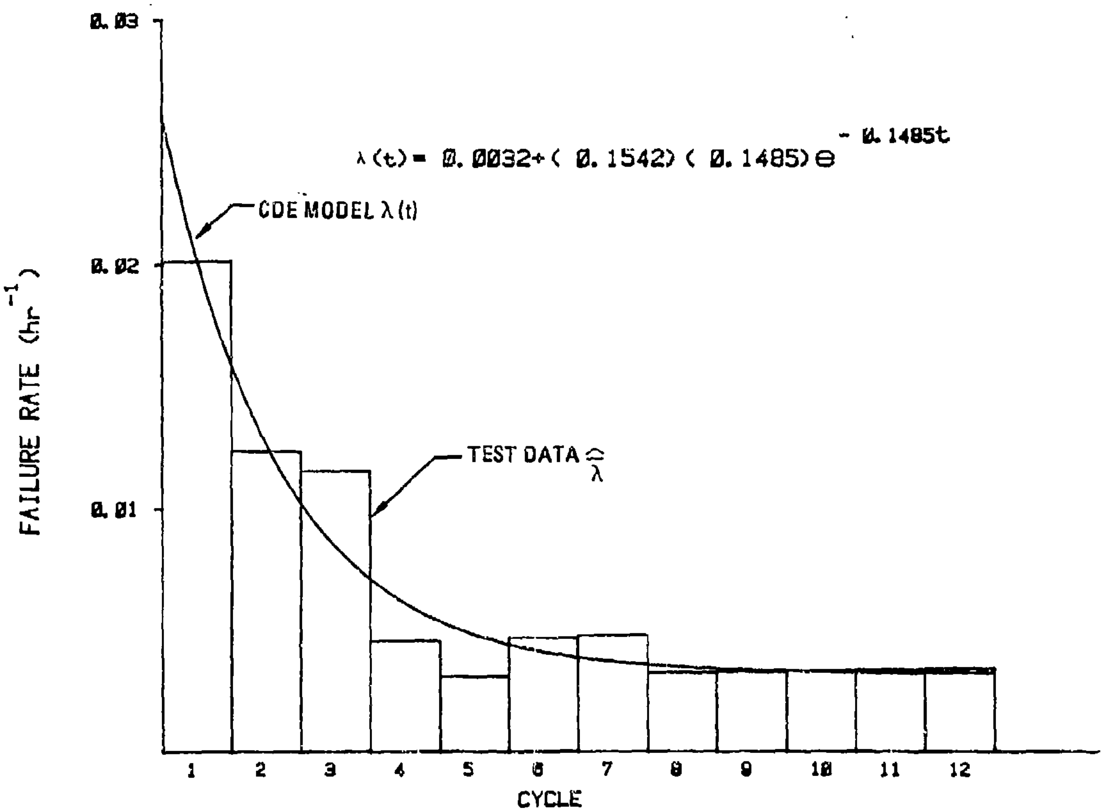

Figure 58. HUD DP Failure Rates for Burn-In (First Failure)

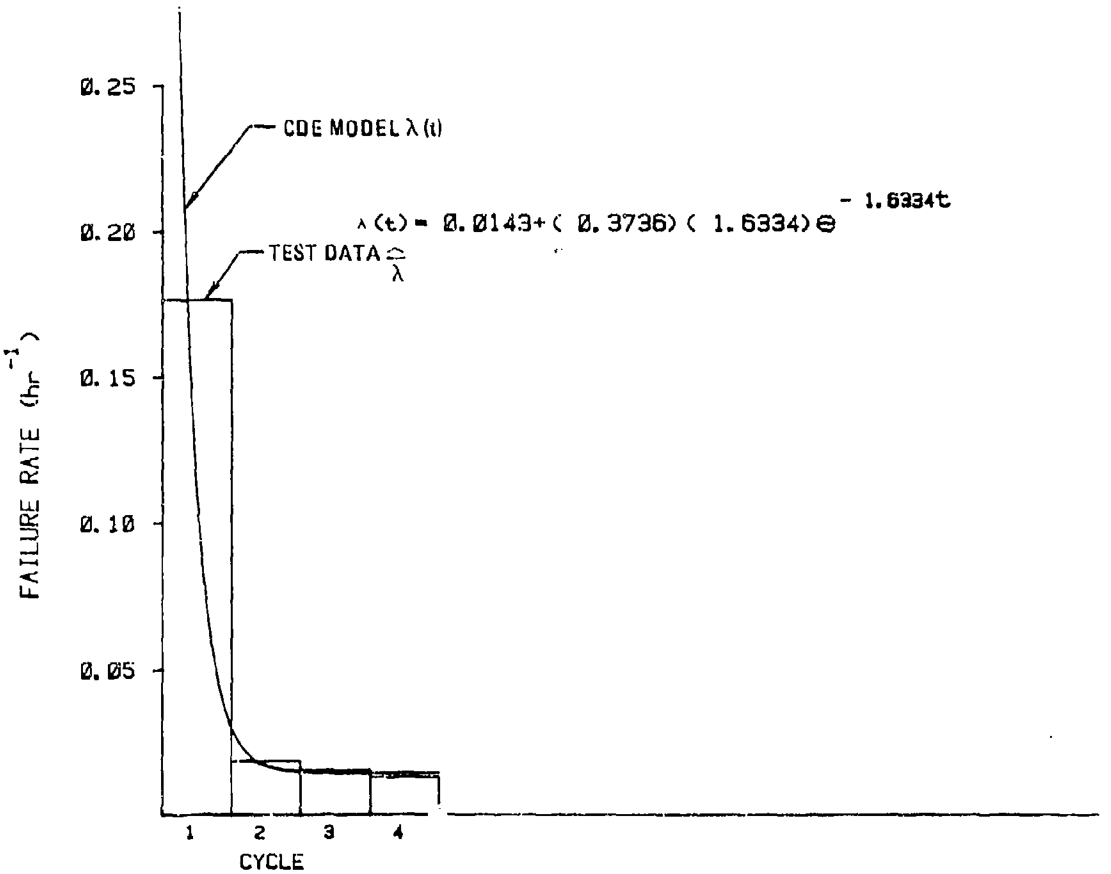

Figure 59. INS IMU Failure Rates for Burn-In (First Failure)

Unless the sample failure rate becomes relatively constant, the model will estimate a decreasing failure rate with a value of zero for constant failure rate (a_0). An example is shown in Figure 60. This is not unexpected since the model should not predict a constant failure rate which does not appear in the data. This does not mean that the equipment has a constant failure rate of zero. The implication is that the constant failure rate is not estimatable from the data.

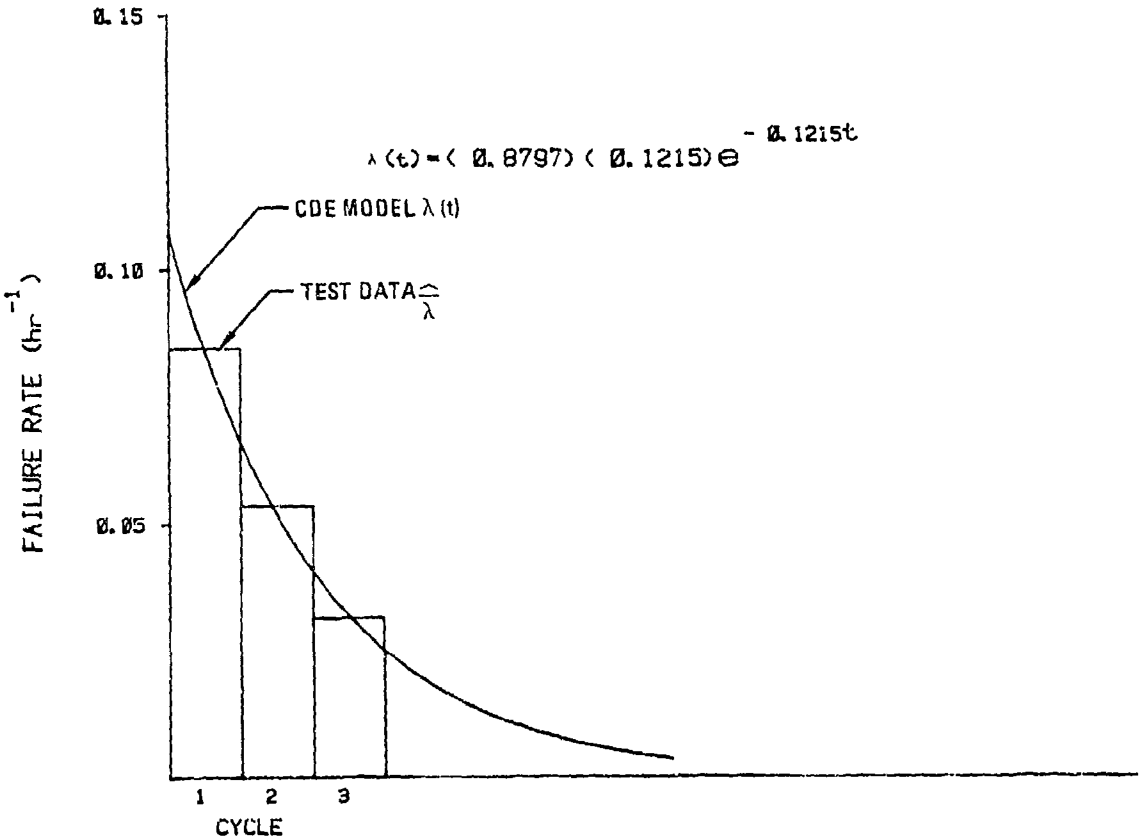

Figure 60. INU Failure Rates (First Failure)

In Figure 61, an example of a non-decreasing failure rate is shown. Here, the model correctly predicts a constant failure rate for all cycles.

3. EBI EFFECTIVENESS MEASURES

Using the parameter estimates developed in the previous section, the burn-in effectiveness measures of Appendix A can be calculated for the burn-in results. It should be remembered that, since the model is an approximation of the failure distribution and the parameters are estimates, the effectiveness measures are also estimates of their respective quantities.

a. Produced Fraction Defective - The produced fraction defective (PFD) is calculated using Equation A-9 of Appendix A and the estimate of the parameter a_1 for the time to first failure distribution. The PFD can be viewed as the probability a unit contains one or more defects prior to burn-in or as the fraction of the production population which contains one or more defects. The PFD for the various equipments is shown in Table 12. It ranges from a low of 0.05 for the AFCS pitch computer to 0.71 for the FGS pitch computer. The average for all equipment is 0.32.

The average PFD for the military equipment is 0.14 and for commercial equipment is 0.53. In general, the PFD for military equipment is lower than commercial equipment. Comparing similar equipments (INS IMU vs INU and FGS computers vs AFCS computers) also shows the military equipment to have a lower PFD.

TABLE 12. PRODUCED FRACTION DEFECTIVE

Use	Equipment	Produced Fraction Defective	Parts Count
Military	HUD DU	0.11	965
	HUD SDP	0.14	931
	INS IMU	0.31	3125
	INS NCI	0.13	472
	AFCS Roll/Yaw Computer	0.09	1246
	AFCS Pitch Computer	0.05	994
Commercial	INU	0.59	4537
	FGS Pitch Computer	0.71	4872
	FGS Roll Computer	0.59	3894
	FGS Yaw Computer	0.46	2682
	DADC	0.28	1600

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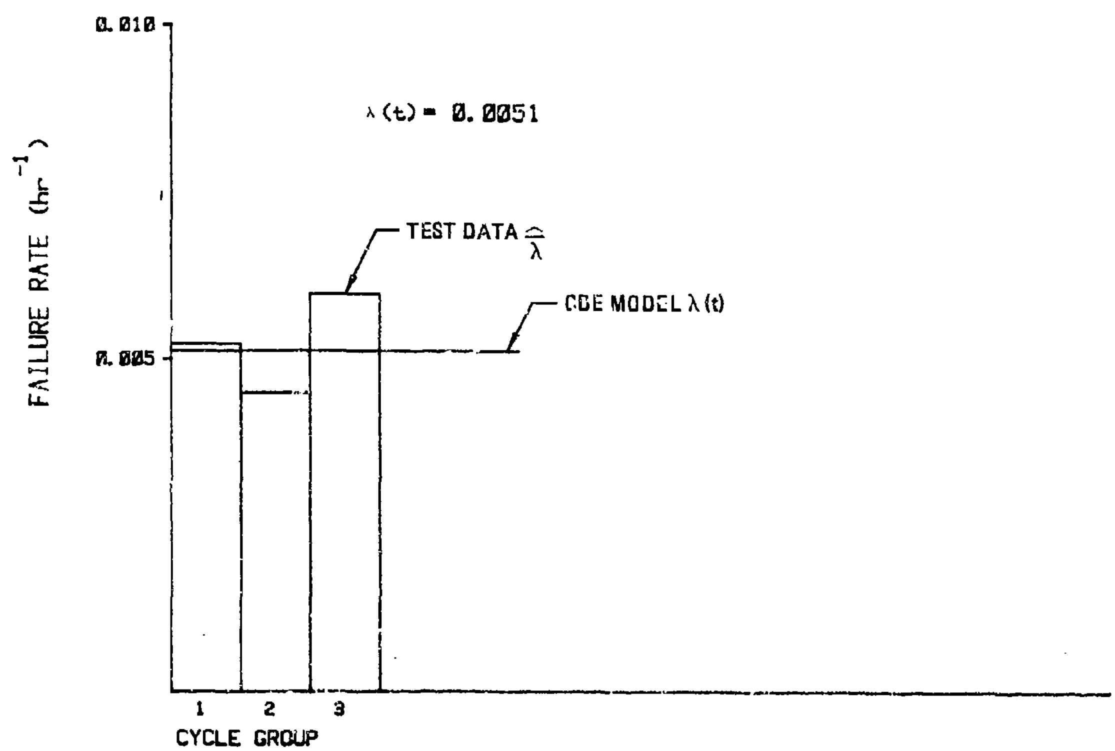

Figure 61. FGS Yaw Computer Failure Rates (Second Failure)

The differences in PFD can be partly explained by the differing numbers of parts in the various units. The graph of Figure 62 shows a plot of the PFD of Table 12 versus the unit part count (from Section III). The graph indicates that the higher PFD for commercial equipment can be partially explained by the larger numbers of parts in those units. The results of linear regression on the data for all units, military only and commercial only, are also shown in Figure 62. The equations are indicated, along with the correlation coefficient (r) and the standard error of the estimate (S). Although based on a small sample, the equations could be used to provide a gross estimate of the PFD based on unit part count.

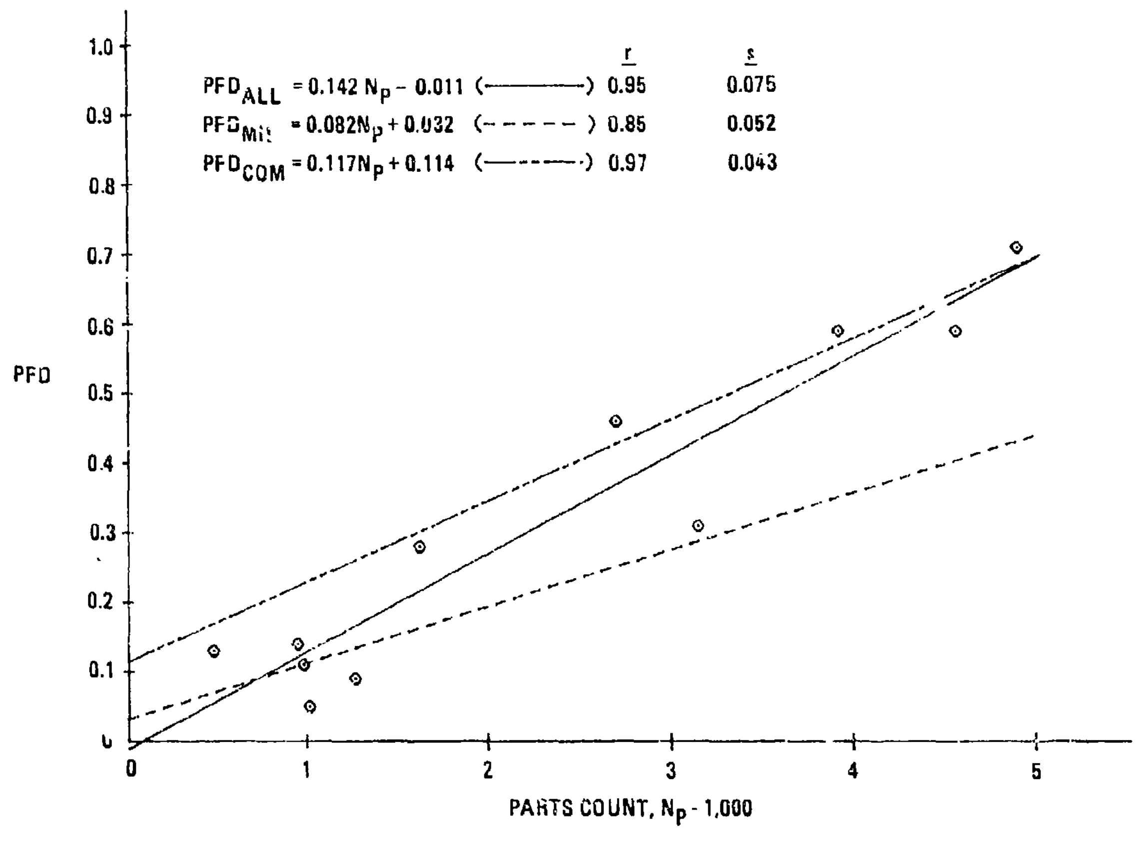

Figure 62. Produced Fraction Defective vs Parts Count

b. Surviving Fraction Defective - The surviving fraction defective (SFD) is calculated using Equation A-8 of Appendix A and the parameters estimated in the previous section. The SFD for the equipment is shown in Tables 13 and 14. For each equipment the SFD is calculated for time equal to zero (column 0) and for the time at the end of each cycle (1, 2, 3, ...). The SFD for each

burn-in test and failure distribution (1st failure, 2nd failure, etc.) is provided. The SFD shown is the probability a unit is defective given the unit has completed the cycle indicated in the column heading.

From Table 13, the produced fraction defective (PFD) for the HUD-DU is 0.11 (Fail No. 1 and Cycle 0). DU units which survive two cycles without failure have a probability of being defective of 0.01. After first failure and repair, the fraction defective is 0.07 (Fail No. 2 and cycle 0). DU which survive one cycle after the first repair have a probability of 0.02 of being defective.

The SFD for the other equipments may be interpreted in a similar fashion. The DADC data was not available on a per cycle basis, and was provided in increments of 25 operating hours. The SFD for the DADC shown in Table 14 is for 25 hour intervals and not cycles as for the other units.

The data in the tables can be viewed in two ways. Each line read horizontally shows the decrease in fraction defective as a function of the number of successful cycles on the unit. The column headed 0 read from top to bottom for an equipment shows the change in fraction defective as a function of failure and repair (Fail No. 2, 3) and from test to test, if there is more than one burn-in test. For example, the fraction defective entering the DU twelve-cycle burn-in is 0.11. After one failure the fraction defective is 0.07 and the fraction defective entering the subsequent eight-cycle burn-in is 0.05.

From Table 13, it is seen that the fraction defective for units which survive the first few cycles of burn-in rapidly approacnes zero (Fail No. 1). This is also true for units which fail and are repaired (Fail Nos. 2 and 3). It is clear from this table that the units which survive enough burn-in cycles to assure some acceptably low fraction defective should be removed from test, as further testing (cycling) does not reduce the fraction defective. Units which fail should be required to complete enough cycles failure free to assure an acceptably low fraction defective. For example, based on the SFD provided in Table 13 for the HUD-SDP and a SFD requirement of 0.01, the twelve cycle burn-in test could be changed to four cycles, with the last three consecutively failure-free. The SFD for units which pass the four cycles is 0.01 (Fail 1, column 4). The SFD for units which have failed and pass three cycles is also 0.01 (Fail 2, Column 3). This assumes that the SFD for Fail No. 3, 4, etc., is less than or equal to the SFD for Fail 2. This assumption is reinforced by the fact that the SFD in Tables 13 and 14 generally decrease with Fail No. for a given equipment and test. The single exception is the seven-cycle test for the INS-IMU, where the fraction defective after failure and repair (.22) is greater than the produced fraction defective (.06). This is a consequence of "imperfect repair" discussed earlier and indicates the requirement for some failure-free burn-in after failure and repair.

TABLE 13. SURVIVING FRACTION DEFECTIVE FOR MILITARY EQUIPMENT

Equipment	Burn-In (cycles)	Fail No.	Surviving Fraction Defective												
			0	1	2	3	4	5	6	7	8	9	10	11	12
HUD DU	12	1	0.11	0.03	0.01	0	0	0	0	0	0	0	0	0	0
		2	0.07	0.02	0	0	0	0	0	0	0	0	0	0	0
	8	1	0.05	0	0	0	0	0	0	0	0	–	–	–	–
		2	0.04	0	0	0	0	0	0	0	0	–	–	–	–
HUD SDP	12	1	0.14	0.08	0.05	0.03	0.01	0.01	0	0	0	0	0	0	0
		2	0.09	0.04	0.02	0.01	0	0	0	0	0	0	0	0	0
	8	1	0.14	0.06	0.02	0.01	0	0	0	0	0	–	–	–	–
		2	0.05	0.01	0	0	0	0	0	0	0	–	–	–	–
INS IMU	3	1	0.31	0.01	0	0	–	–	–	–	–	–	–	–	–
		2	0.29	0	0	0	–	–	–	–	–	–	–	–	–
		3	0.30	0	0	0	–	–	–	–	–	–	–	–	–
	7	1	0.06	0.01	0	0	0	0	0	0	–	–	–	–	–
		2	0.22	0.02	0	0	0	0	0	0	–	–	–	–	–
	10	1	0.11	0.06	0.03	0.02	0.01	0.01	0	0	0	0	0	–	–
		2	0.14	0.04	0.01	0	0	0	0	0	0	0	0	–	–
INS NCI	3	1	0.13	0.01	0	0	–	–	–	–	–	–	–	–	–
	7	1	0.09	0.06	0.04	0.02	0.01	0.01	0.01	0	–	–	–	–	–
	10	1	0.03	0	0	0	0	0	0	0	0	0	0	–	–
AFCS Roll/Yaw Computer	9	1	0.09	0.03	0.01	0	0	0	0	0	0	0	–	–	–
AFCS Pitch Computer	9	1	0.05	0.02	0.01	0.01	0	0	0	0	0	0	–	–	–

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TABLE 14. SURVIVING FRACTION DEFECTIVE FOR COMMERCIAL EQUIPMENT

Equipment	Burn-In (cycles)	Fail No.	Surviving Fraction Defective										
			0	1	2	3	4	5	6	7	8	–	12	16
INU	3	1	0.59	0.42	0.28	0.19	–	–	–	–	–	–	–	–
		2	0.46	0.31	0.20	0.12	–	–	–	–	–	–	–	–
		3	0.17	0.01	0	0	–	–	–	–	–	–	–	–
FGS Pitch Computer	16	1	0.71	–	–	–	0.61	–	–	–	0.52	–	0.44	0.36
		2	0.20	–	–	–	0	–	–	–	0	–	0	0
FGS Roll Computer	16	1	0.59	–	–	–	0.48	–	–	–	0.39	–	0.30	0.23
		2	0.03	–	–	–	0	–	–	–	0	–	0	0
FGS Yaw Computer	16	1	0.46	–	–	–	0.35	–	–	–	0.27	–	0.20	0.15
		2	0	–	–	–	0	–	–	–	0	–	0	0
DADC	21	1	0.28	0.12	0.05	0.02	0.01	0	0	0	0	–	–	–
		2	0.04	0.02	0.01	0	0	0	0	0	0	–	–	–

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Referring to Table 13 and the SFD for Fail No. 1 for each equipment, it is clear that the length of burn-in could be reduced for units which do not fail, without increasing the SFD. In general, current practice appears to provide more screening than necessary on units which do not fail. The reduced number of cycles must be coupled with a fail-free requirement on failed and repaired units to insure an adequate SFD for the whole production population. Table 15 indicates how the burn-in would be changed for an SFD requirement of 0.01 and 0.00 for the equipment and tests of Table 13.

Table 14 shows the SFD results for the commercial equipment. Due to the testing method of the FGS equipments (once every four cycles) and the lack of test results by cycle for the DADC (25 hour intervals) direct comparison with other equipment on a per cycle basis is not possible. Results for the INU in Table 14 indicate that additional cycles would improve the SFD for units which survive the screen. The number of additional cycles required is unclear since the constant failure rate term is not estimatable from the data. The SFD for failed and repaired units (Fail No. 2, 3) decreases with additional cycling indicating that the reburn-in or imperfect repair is present in the commercial systems also.

Two of the military systems (HUD and INS) are subjected to sequential burn-in tests. The HUD twelve-cycle test is conducted at the LRU level, followed by an LRU AT and the eight-cycle test conducted at the set level (DU and SDP tested as a system). The INS three-cycle test is conducted at the LRU level followed by a random vibration test, an AT, and the seven-cycle test, all conducted at the LRU level. The ten-cycle test is done at the set level.

Referring to Table 13 and noting the fraction defective entering the different tests (Fail No. 1, column 0) for the HUD and INS systems, the fraction defective generally decreases after each burn-in test. In the case of the HUD-SDP, the produced fraction defective is 0.14 and the fraction defective after the twelve-cycle test (prior to eight-cycle test) is also 0.14. Since the SFD tends to approach zero with each cycle, the fraction defective prior to subsequent test should be small relative to the fraction defective entering the previous test. This does not appear to be the case. As mentioned, the HUD-SDP has the same fraction defective before and after the twelve-cycle test.

In the case of the INS-IMU, the fraction defective after the seven-cycle test (.11) is greater than the fraction defective before the seven-cycle test (.06). While the exact cause of this behavior is unknown, changes in test type (LRU vs Set) and intervening tests (vibration, AT) may have some effect.

TABLE 15. BURN-IN TEST vs SFD REQUIREMENT

Equipment	Test (cycles)	SFD	
		0.01	0
HUD DU	12	2 cycles Fail Free	3 cycles Last 2 Fail Free
	8	1 cycle Fail Free	1 cycle Fail Free
HUD SDP	12	4 cycles Last 3 Fail Free	6 cycles Last 4 Fail Free
	8	3 cycles Last 1 Fail Free	4 cycles Last 2 Fail Free
INS IMU	3	1 cycle Fail Free	2 cycles Last 1 Fail Free
	7	2 cycles Fail Free	2 cycles Fail Free
	10	4 cycles Last 2 Fail Free	6 cycles Last 3 Fail Free
INS NCI	3	1 cycle Fail Free	2 cycles Fail Free
	7	4 cycles Fail Free	7 cycles Fail Free
	10	1 cycle Fail Free	1 cycle Fail Free
AFCS Roll/Yaw Computer	9	2 cycles Fail Free	3 cycles Fail Free
AFCS Pitch Computer	9	2 cycles Fail Free	4 cycles Fail Free

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c. Defect versus Failure - In the conduct of burn-in tests extensive failure analysis may be conducted on failed components and assemblies, in order to determine the cause of failure which may provide insight as to possible corrective action. Since in depth failure analysis requires the use of assets (time, money, facilities), it would be useful to know if a particular failure is likely to represent a defect as opposed to a chance failure.

The probability that a failure is also a defect may be calculated using Equation A-10 from Appendix A and the model parameters. The results for the equipments are shown in Tables 16 and 17. The column headings (1, 2, 3, ...) represent the time at the end of Cycle 1, 2, 3, ... etc. Column 0 represents the start of Cycle 1. For example, if the HUD-DU failed at the end of Cycle 2, the probability the failure is a defect is 0.14 for the 12-cycle test. The intervals for the DADC are 25 hours as opposed to cycles as in previous tables.

Failure analysis activity should be allocated to those failures which occur in cycles where the probability of observing a defect is acceptably high. Exactly what level is acceptable will depend on the cost and expectations of the failure analysis to indicate constructive corrective action and other subjective considerations. It is not unreasonable to require that the probability of a defect be greater than 0.10 for failure analysis to be performed. If this is the criterion, then failures which occur in cycles to the left of the dark line in Table 16 and 17 would be analyzed. Failures occurring to the right would not require analysis.

TABLE 16. PROBABILITY A FAILURE IS A DEFECT FOR MILITARY SYSTEMS

Equipment	Burn-In (cycles)	Fail No.	Probability a Failure is a Defect												
			0	1	2	3	4	5	6	7	8	9	10	11	12
HUD DU	12	1	0.79	0.44	0.14	0.03	0.01	0	0	0	0	0	0	0	0
		2	0.69	0.34	0.11	0.03	0.01	0	0	0	0	0	0	0	0
	8	1	0.99	0	0	0	0	0	0	0	0	–	–	–	–
		2	0.99	0	0	0	0	0	0	0	0	–	–	–	–
HUD SDP	12	1	0.88	0.80	0.69	0.55	0.40	0.27	0.17	0.10	0.06	0.03	0.02	0.01	0.01
		2	0.84	0.69	0.48	0.27	0.14	0.06	0.03	0.01	0.01	0	0	0	0
	8	1	0.88	0.74	0.53	0.31	0.15	0.07	0.03	0.01	0.01	–	–	–	–
		2	0.77	0.36	0.09	0.02	0	0	0	0	0	–	–	–	–
INS IMU	3	1	0.98	0.52	0.03	0	–	–	–	–	–	–	–	–	–
		2	1.00	0	0	0	–	–	–	–	–	–	–	–	–
		3	0.99	0	0	0	–	–	–	–	–	–	–	–	–
	7	1	0.82	0.32	0.05	0.01	0	0	0	0	–	–	–	–	–
		2	0.94	0.57	0.10	0.01	0	0	0	0	–	–	–	–	–
	10	1	0.82	0.71	0.56	0.41	0.27	0.16	0.09	0.05	0.03	0.02	0.01	–	–
		2	0.91	0.71	0.38	0.13	0.04	0.01	0	0	0	0	0	–	–
INS NCI	3	1	0.98	0.66	0.06	0	–	–	–	–	–	–	–	–	–
	7	1	0.89	0.83	0.76	0.66	0.54	0.42	0.31	0.21	–	–	–	–	–
	10	1	0.99	0	0	0	0	0	0	0	0	0	0	–	–
AFCS Roll/Yaw Computer	9	1	0.91	0.77	0.53	0.27	0.11	0.04	0.01	0	0	0	–	–	–
AFCS Pitch Computer	9	1	0.89	0.79	0.65	0.47	0.30	0.17	0.09	0.05	0.02	0.01	–	–	–

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Regardless of the criteria used, it is clear that failure analysis assets should be allocated to failures which occur in the early burn-in cycles. As seen in Table 17, where steady-state or constant failure rate is not achieved during burn-in (INU and FGS) the constant failure rate (a_0) is estimated to be zero, which implies all failures are defects. This results in the indication that all failures are defects with probability 1.0. For situations where the constant failure rate is inestimatable the defect probabilities provide a degenerate solution (1.0) and are not representative of the actual situation.

TABLE 17. PROBABILITY A FAILURE IS A DEFECT FOR COMMERCIAL SYSTEMS

Equipment	Burn-In (cycles)	Fail No.	Probability a Failure is a Defect											
			0	1	2	3	4	5	6	7	8	–	12	16
INU	3	1	1.00	1.00	1.00	1.00	–	–	–	–	–	–	–	–
		2	1.00	1.00	1.00	1.00	–	–	–	–	–	–	–	–
		3	0.86	0.20	0.01	0	–	–	–	–	–	–	–	–
FGS Pitch Computer	16	1	1.00	–	–	–	1.00	–	–	–	1.00	–	1.00	1.00
		2	0.98	–	–	–	0	–	–	–	0	–	0	0
FGS Roll Computer	16	1	1.00	–	–	–	1.00	–	–	–	1.00	–	1.00	1.00
		2	0.82	–	–	–	0	–	–	–	0	–	0	0
FGS Yaw Computer	16	1	1.00	–	–	–	1.00	–	–	–	1.00	–	1.00	1.00
		2	0	–	–	–	0	–	–	–	0	–	0	0
DADC	21	1	0.86	0.70	0.47	0.26	0.12	0.05	0.02	0.01	0	–	–	–
		2	0	0	0	0	0	0	0	0	0	–	–	–

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d. <u>Screen Improvement Factor</u> - In order to assess efficiency of the burn-in temperature cycle in terms of the reduction in fraction defective the Screen Improvement Factor (SIF) is provided. The SIF, defined in Equation A-11 of Appendix A, is the ratio of the reduction in fraction defective provided by the burn-in to that which would be provided by a "perfect" burn-in test. The SIF values for the various equipments and tests are shown in Table 18. For example, the HUD-DU in twelve cycle burn-in, the fraction defective is reduced by 78% after competing Cycle 1 successfully and by 100% or to approximately zero after successfully completing only four cycles. For the military systems (HUD, INS, AFCS), the SIF is 90% or greater after only four or five cycles. (Values for the INU and FGS should not be considered representative, since the estimated steady-state failure rate (a_o) is zero providing a degenerate solution.)

4. FAILURE RATE BY DEFECT TYPE

In order to evaluate the effectiveness of burn-in on the type of defects present in electronic equipment, the overall discrete failure rate of Section 1 can be decomposed based on the defect type: part, workmanship, design and "could not duplicate" (CND). The could-not-duplicate type represents those instances when a malfunction occurs but the unit performs satisfactorily after retest without repair or adjustment.

TABLE 18. SCREEN IMPROVEMENT FACTOR

Equipment	Burn-In (cycles)	Screen Improvement Factor (percent)													
		1	2	3	4	5	6	7	8	9	10	11	12	–	16
HUD DU	12	78	96	99	100	100	100	100	100	100	100	100	100	–	–
	8	100	100	100	100	100	100	100	100	–	–	–	–	–	–
HUD SDP	12	43	68	82	90	94	97	99	99	99	100	100	100	–	–
	8	59	83	93	97	99	99	100	100	–	–	–	–	–	–
INS IMU	3	97	100	100	–	–	–	–	–	–	–	–	–	–	–
	7	90	98	100	100	100	100	100	–	–	–	–	–	–	–
	10	45	70	84	91	96	97	99	99	100	100	–	–	–	–
INS NCI	3	96	100	100	–	–	–	–	–	–	–	–	–	–	–
	7	38	61	76	86	91	94	97	–	–	–	–	–	–	–
	10	100	100	100	100	100	100	100	100	100	100	–	–	–	–
AFCS Roll/Yaw Computer	9	66	89	97	99	100	100	100	100	100	–	–	–	–	–
AFCS Pitch Computer	9	50	77	90	94	98	98	100	100	100	–	–	–	–	–
INU	3	29	52	68	–	–	–	–	–	–	–	–	–	–	–
FGS Pitch Computer	16	–	–	–	13	–	–	–	26	–	–	–	38	–	49
FGS Roll Computer	16	–	–	–	19	–	–	–	35	–	–	–	50	–	61
FGS Yaw Computer	16	–	–	–	22	–	–	–	41	–	–	–	56	–	67

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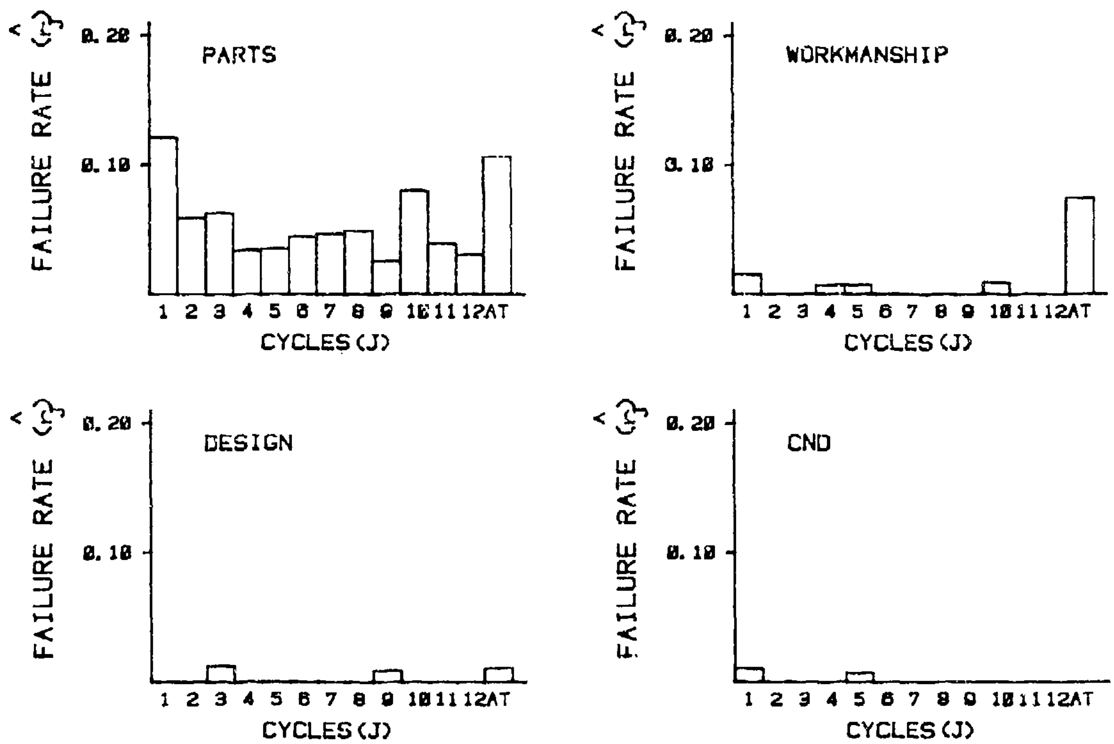
Equation A-14 of Appendix A was used in Figures 63 through 75 to estimate failure rates by defect type. The data is based on the failure rate for first failure of the units.

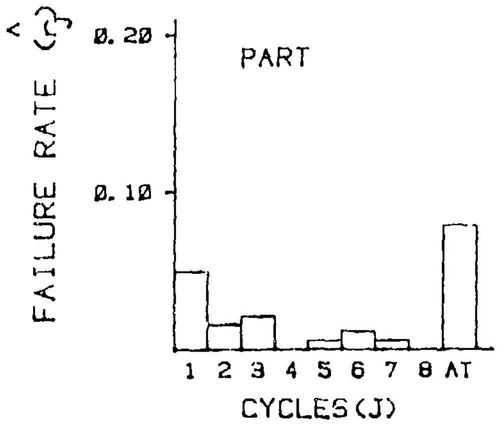
It is observed that in each instance the decreasing system failure rate is provided primarily by the decreasing part failure rate. This indicates that the improved equipment reliability provided by the burn-in test is primarily obtained by the identification and removal of defective parts. The failure rate of the workmanship defects appears to decrease slightly (Figures 66, 69, 71, 72, and 75) or remain relatively constant (Figures 63, 64, 68, and 70). In all cases, the failure rate due to workmanship is less than the part failure rate. A comparison of relatively high steady state failure rates (Figures 63, 68, 73, 74, and 75) with the low steady state failure rates (Figures 70, 71, and 72) indicates that the difference is attributable to part failure rates. Comparing Figure 63 with Figure 71, the failure rates due to workmanship are comparable, while the part failure rates are significantly different. The CND failure rate is relatively constant for all units. As might be expected, the removal of units for a momentary malfunction does not improve the population reliability.

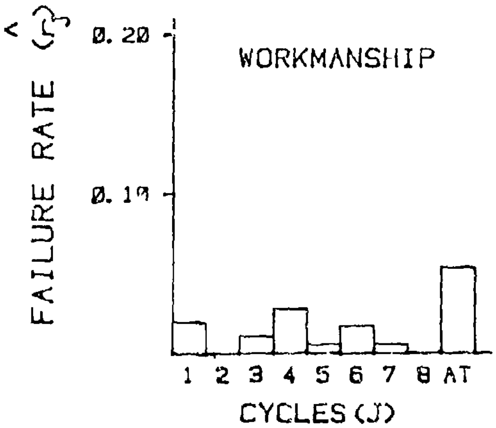
The contribution to the overall failure rate provided by design defects is not significant. Only two systems (Figures 63 and 69) identified any design defects. Since all data was taken from mature production processes (> 200 units produced) this is not unexpected.



CYCLES (J)	1	2	3	4	5	6	7	8	9	10	11	12	AT
PARTS	24	10	10	5	5	6	6	6	3	9	4	3	10
WORK	3	0	0	1	1	0	0	0	0	1	0	0	7
DESIGN	0	0	2	0	0	0	0	0	1	0	0	0	1
CND	2	0	0	0	1	0	0	0	0	0	0	0	0
UNITS (M_J)	198	169	159	147	141	134	128	122	116	112	102	98	94

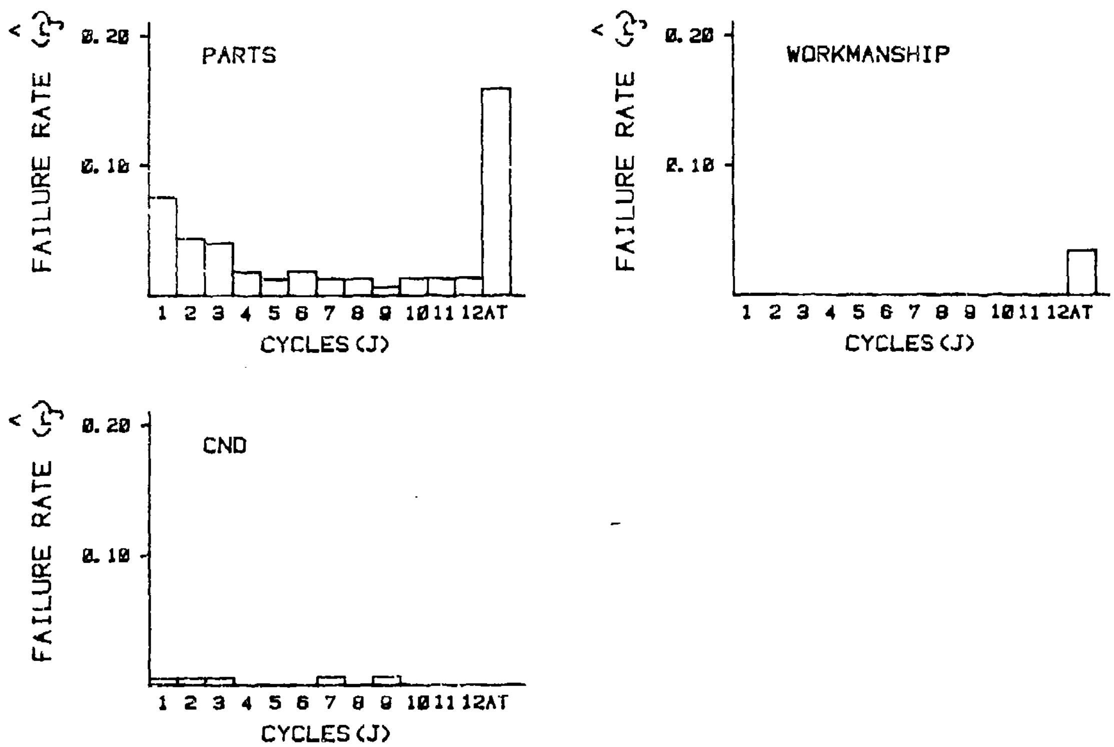
Figure 63. HUD DU Failure Rate by Defect Type (12 Cycle Burn-In)





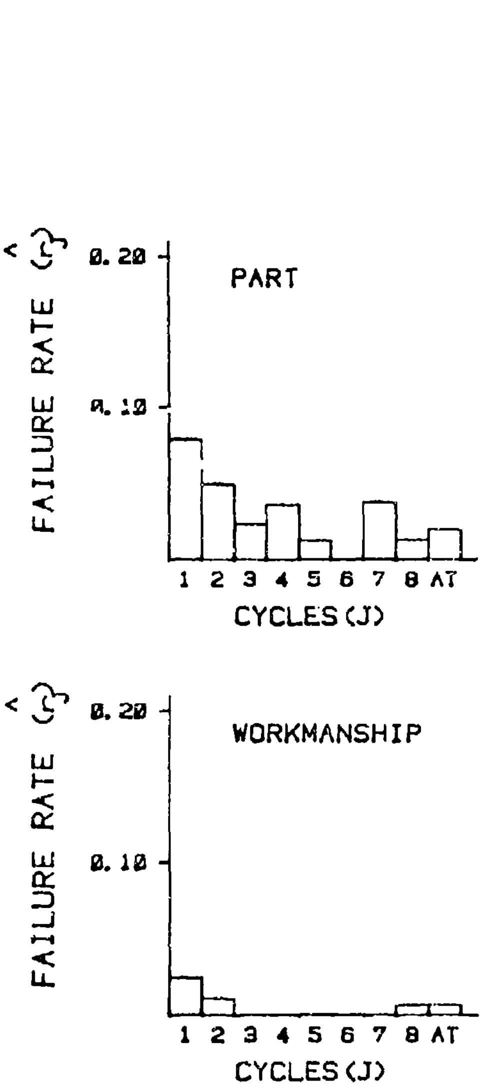
CYCLES (J)	1	2	3	4	5	6	7	8	AT
PART	1Ø	3	4	Ø	1	2	1	Ø	13
WORK	4	Ø	2	5	1	3	1	Ø	9
UNITS (M J)	2Ø3	189	186	18Ø	175	173	168	166	166

Figure 64. HUD DU Failure Rate by Defect Type (8 Cycle)



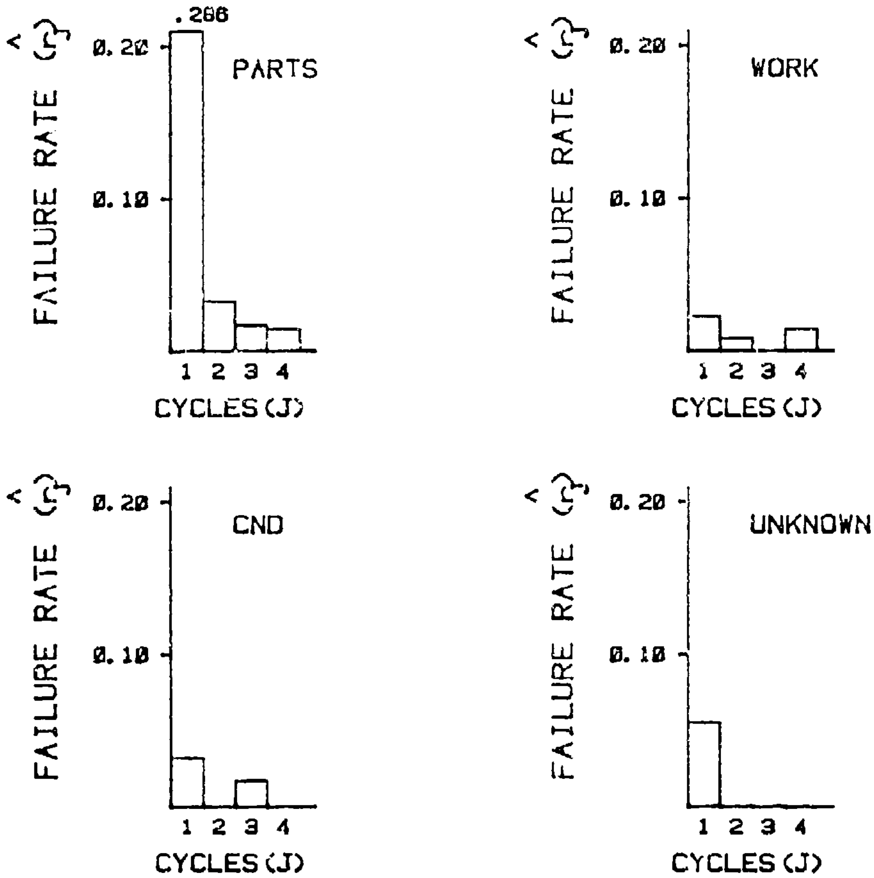
CYCLES (J)	1	2	3	4	5	6	7	8	9	10	11	12	AT
PARTS	15	8	7	3	2	3	2	2	1	2	2	2	23
WORK	0	0	0	0	0	0	0	0	0	0	0	0	5
CND	1	1	1	0	0	0	1	0	1	0	0	0	0
UNITS (M J)	199	183	174	166	163	161	158	155	153	151	149	147	145

Figure 65. HUD SDP Failure Rate by Defect Type (12 Cycle Burn-In)



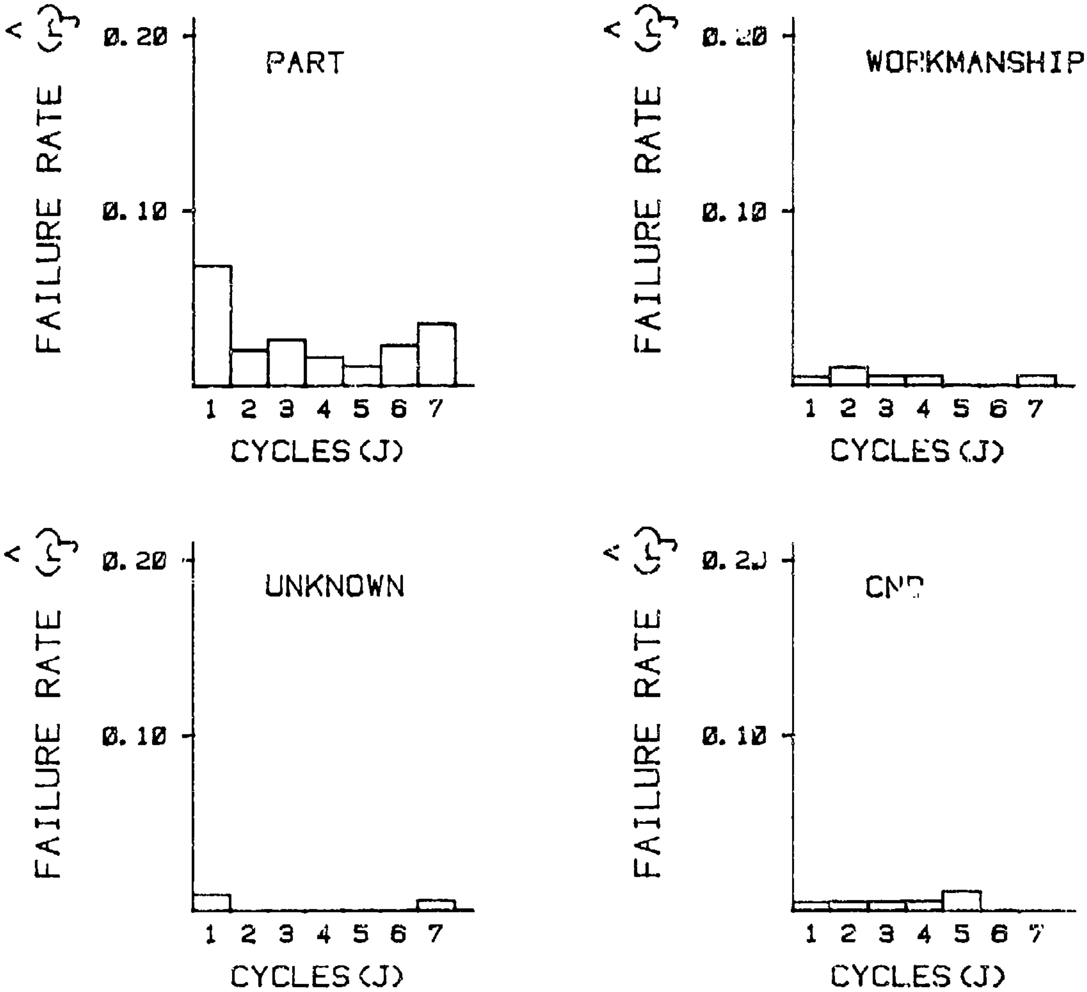
CYCLES (J)	1	2	3	4	5	6	7	8	AT
PART	16	9	4	6	2	0	6	2	3
WORK	5	2	0	0	0	0	0	1	1
UNITS (M_J)	204	183	172	168	162	160	160	154	151

Figure 66. HUDS SDP Failure Rate by Defect Type (8 cycle)



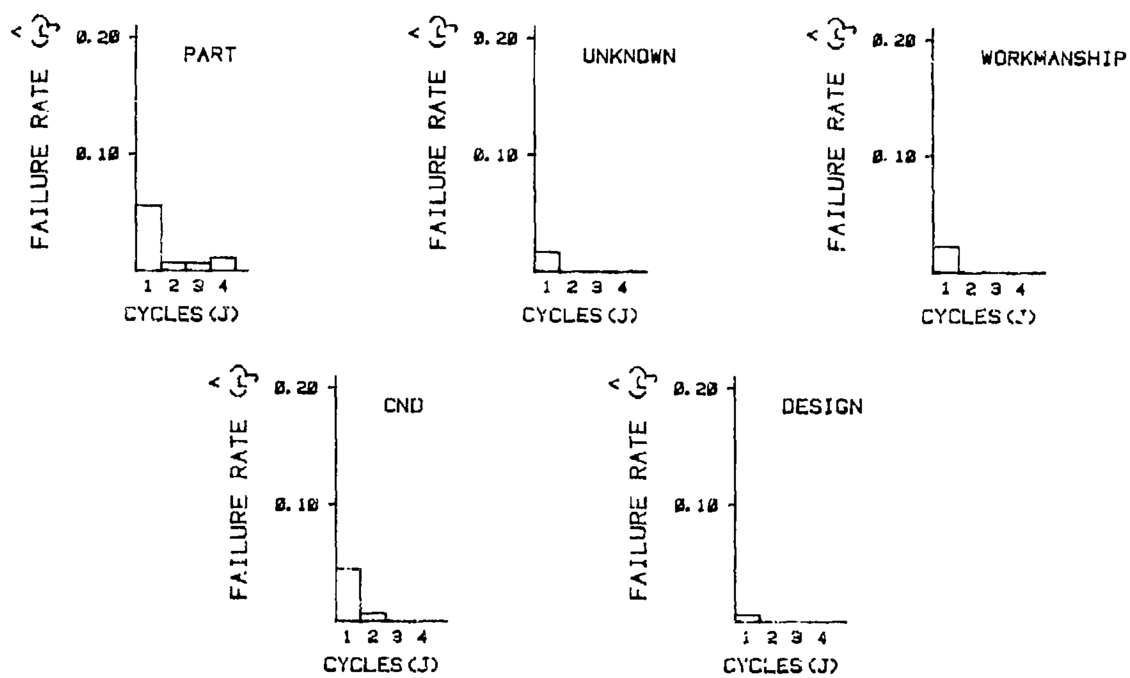
CYCLES (J)	1	2	3	4
PARTS	62	4	2	1
WORK	5	1	0	1
CND	7	0	2	0
UNKNOWN	12	0	0	0
UNITS (M J)	217	121	116	69

Figure 67. INS IMU Failure Rate by Defect Type (3 Cycle)



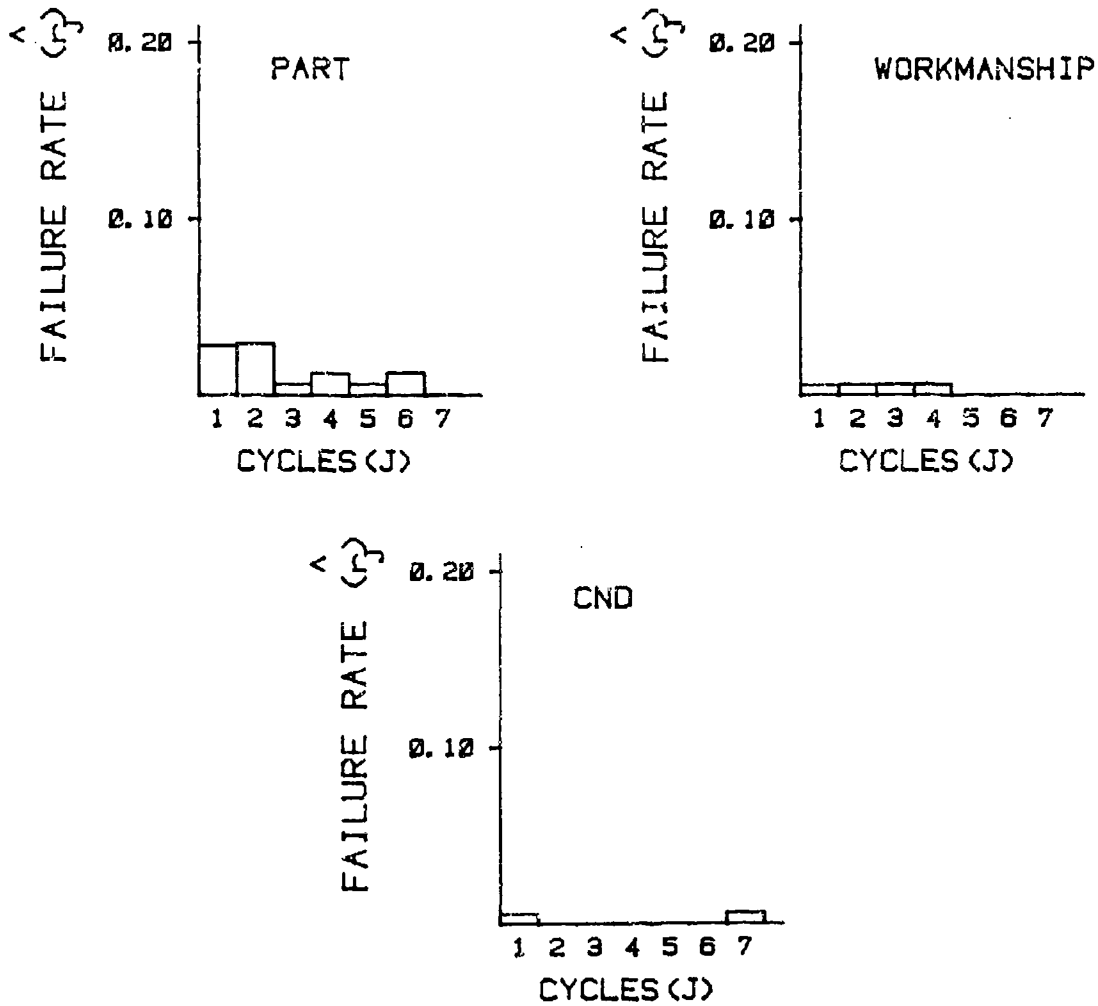
CYCLES (J)	1	2	3	4	5	6	7
PART	15	4	5	3	2	4	6
WORK	1	2	1	1	Ø	Ø	1
UNKNOWN	2	Ø	Ø	Ø	Ø	Ø	1
CND	1	1	1	1	2	Ø	Ø
UNITS (M J)	219	199	192	185	180	176	172

Figure 68. INS IMU Failure Rate by Defect Type (7 Cycle Burn-In)



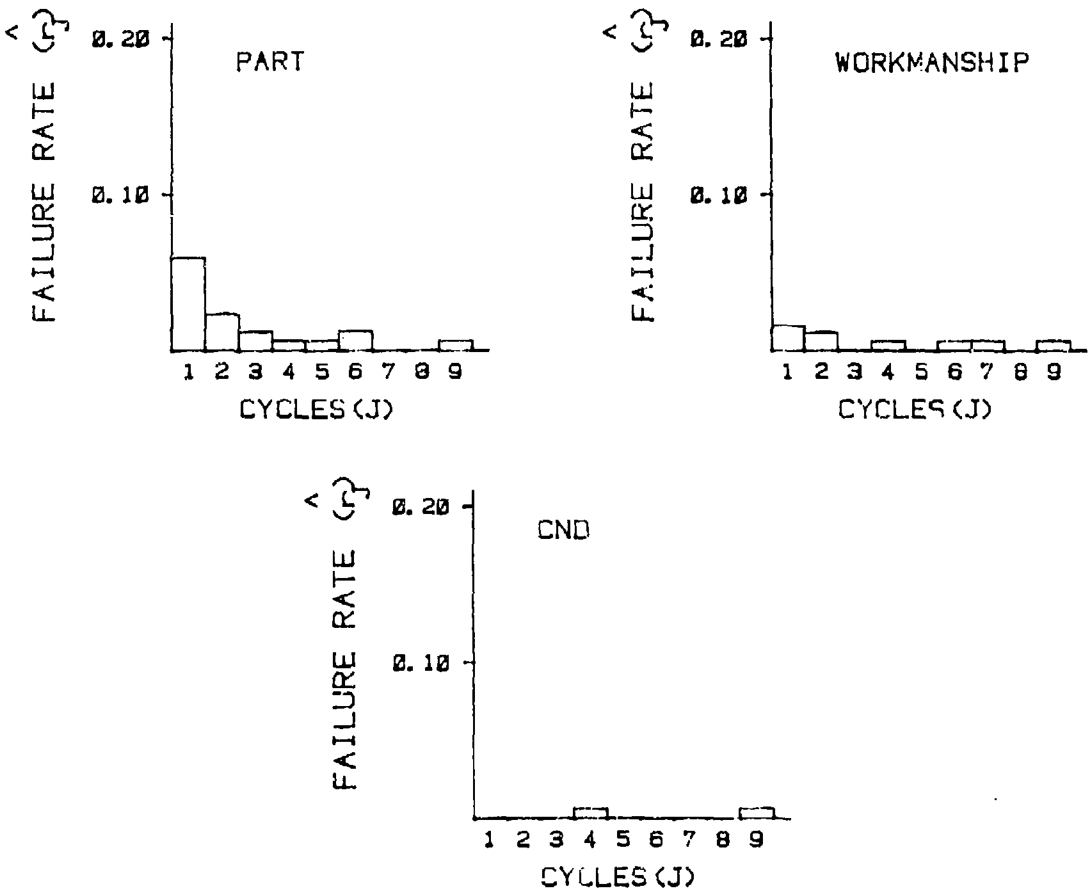
CYCLES (J)	1	2	3	4
PART	1Ø	1	1	1
UNKNOWN	3	Ø	Ø	Ø
WORK	4	Ø	Ø	Ø
CND	8	1	Ø	Ø
DESIGN	1	Ø	Ø	Ø
UNITS (M J)	179	153	151	9Ø

Figure 69. INS NCI Failure Rate by Defect Type (3 Cycle Burn-In)



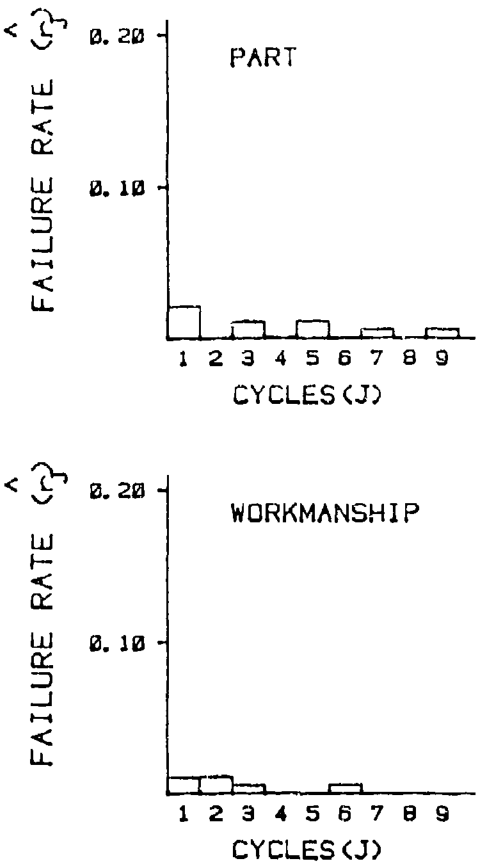
CYCLES (J)	1	2	3	4	5	6	7
PART	5	5	1	2	1	2	0
WORK	1	1	1	1	0	0	0
CND	1	0	0	0	0	0	1
UNITS (M_J)	178	171	165	163	160	159	157

Figure 70. INS NCI Failure Rate by Defect Type (7 Cycle Burn-In)



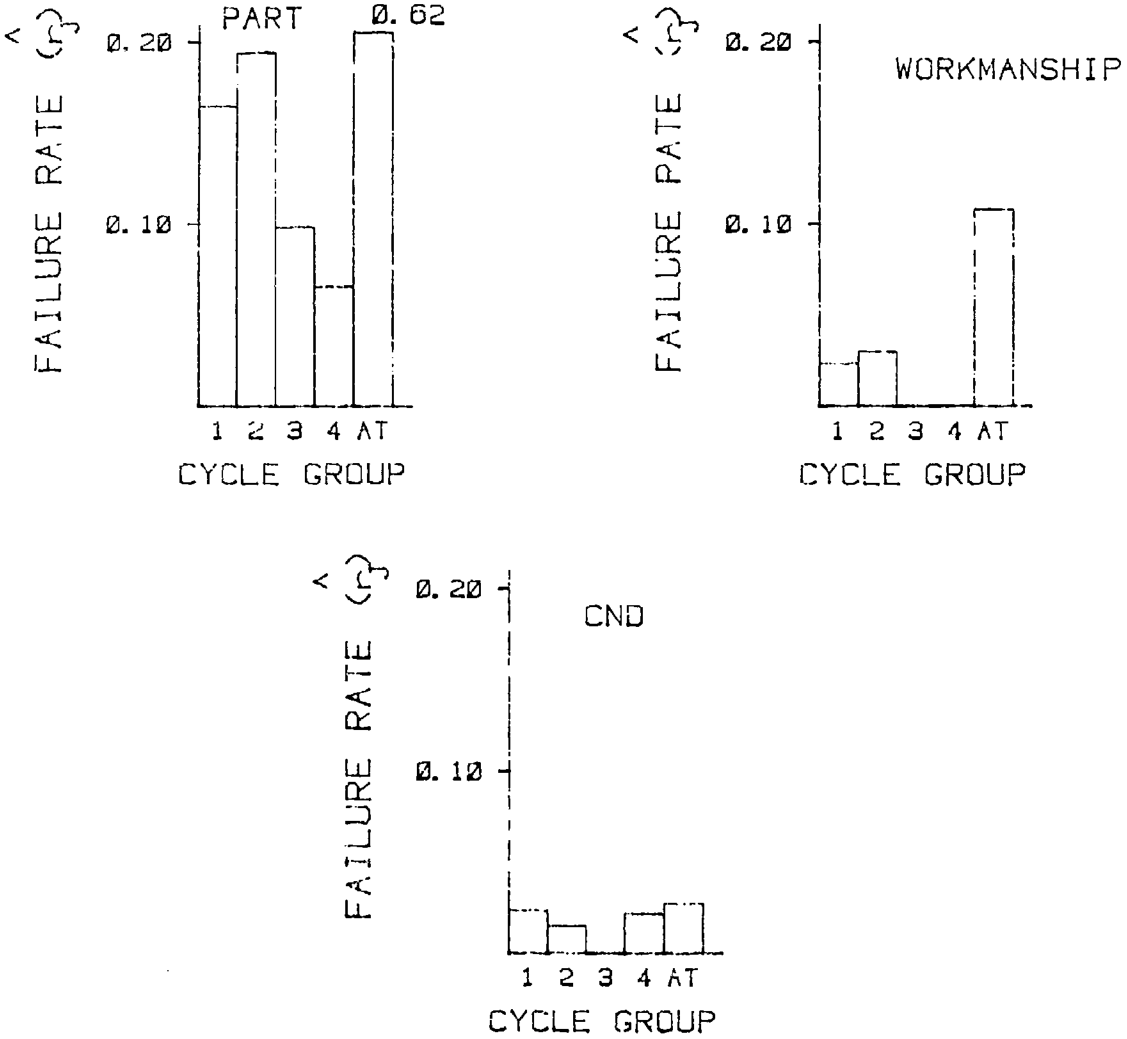
CYCLES (J)	1	2	3	4	5	6	7	8	9
PART	11	4	2	1	1	2	0	0	1
WORK	3	2	0	1	0	1	1	0	1
CND	0	0	0	1	0	0	0	0	1
UNITS (M J)	186	172	166	164	161	160	157	156	156

Figure 71. AFCS Roll/Yaw Computer Failure Rate by Defect Type



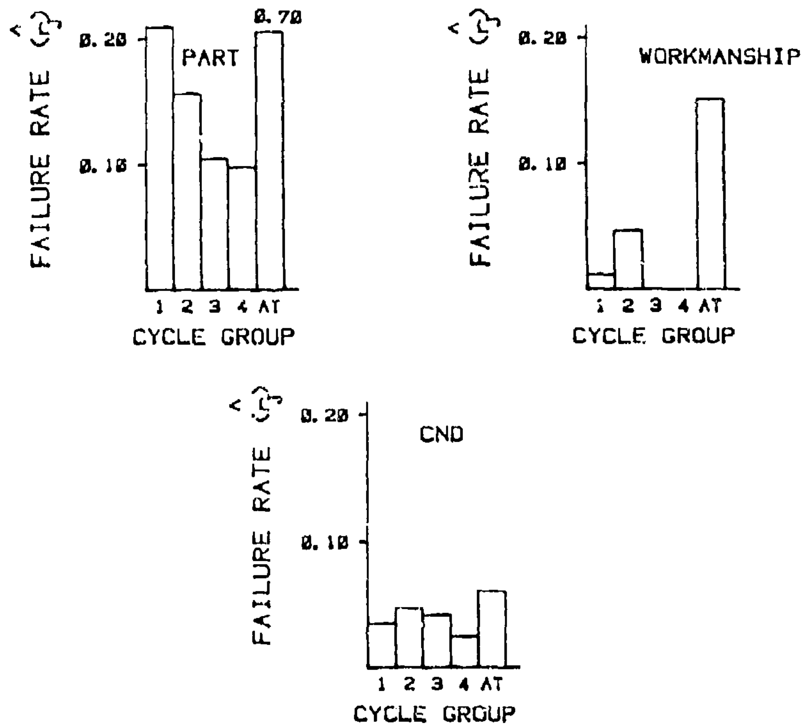
CYCLES (J)	1	2	3	4	5	6	7	8	9
PART	4	0	2	0	2	0	1	0	1
WORK	2	2	1	0	0	1	0	0	0
UNITS (M J)	186	180	178	175	175	173	172	171	171

Figure 72. AFCS Pitch Computer Failure Rate by Defect Type (9 Cycle)



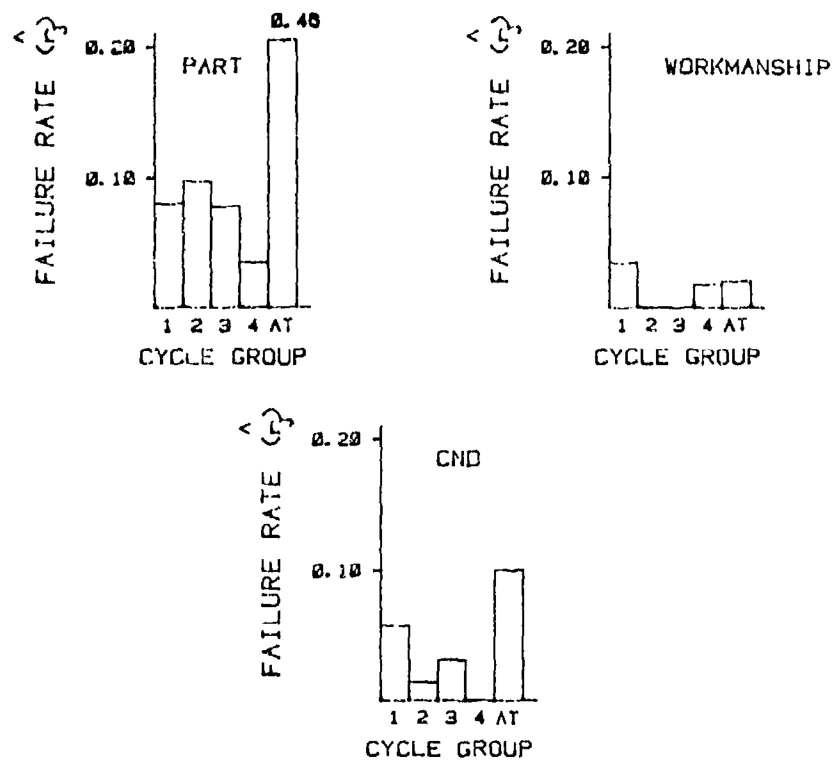
CYCLE GRP	1	2	3	4	AT
PART	14	13	5	3	23
WORK	2	2	Ø	Ø	4
CND	2	1	Ø	1	1
UNITS	85	67	51	46	37

Figure 73. FGS Roll Computer Failure Rate by Defect Type



CYCLE GRP	1	2	3	4	AT
PART	18	10	5	4	23
WORK	1	3	0	0	5
CND	3	3	2	1	2
UNITS	86	64	48	41	33

Figure 74. FGS Pitch Computer Failure Rate by Defect Type

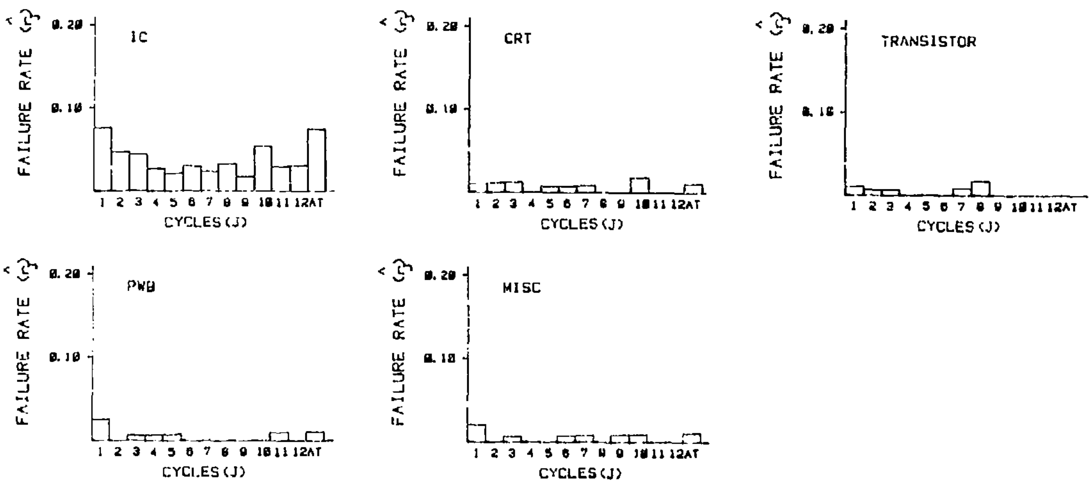


CYCLE GRP	1	2	3	4	AT
PART	7	7	5	2	23
WORK	3	0	0	1	1
CND	5	1	2	0	5
UNITS	87	72	64	57	50

Figure 75. FGS Yaw Computer Failure Rate by Defect Type

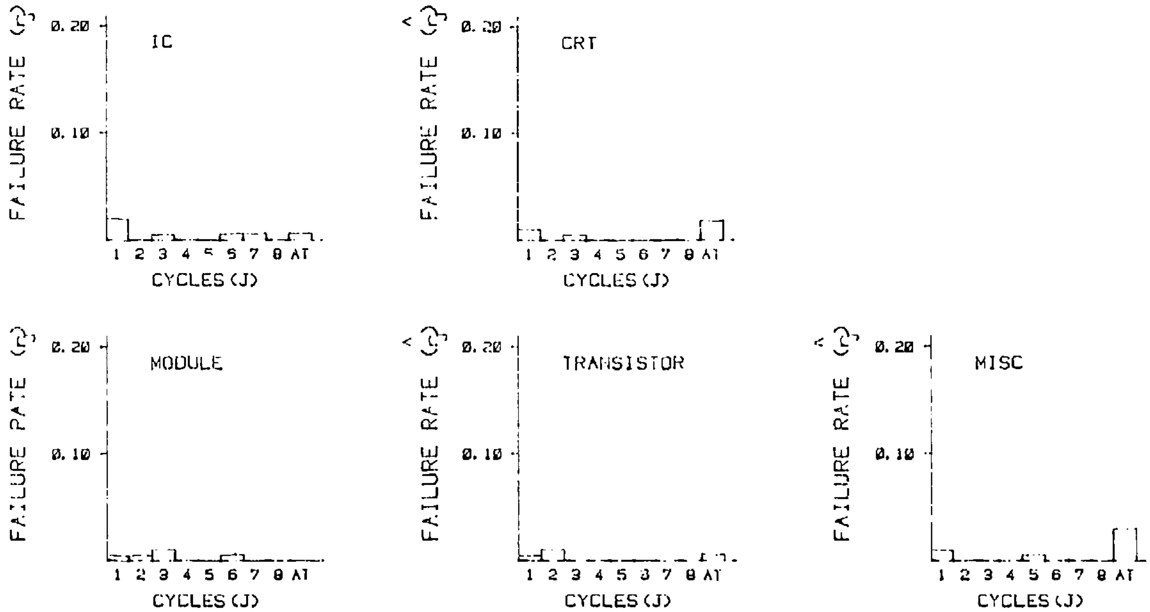
5. FAILURE RATE BY PART CLASS

As shown in the previous section, the decreasing failure rate provided by the burn-in process consists primarily of the removal of defective parts. In the accompanying figures (76-82) the part failure rate is decomposed into various part classes. The part classes are somewhat a function of the particular equipment (CRT in the HUD-DU for example) but generally represent the generic types of parts of which electronic equipment is composed (IC, transistors, modules, printed wiring boards (PWB), etc.). The discrete failure rate is estimated using Equation A-4 of Appendix A and the failure rate for first failure. The figures show that the part failure rate is primarily a reflection of the behavior of the failure rate due to IC's both in its magnitude and temporal behavior (decreasing). While other part classes contribute to the part steady state failure rate, the decreasing behavior (reliability improvement) is caused by the removal of defective IC's.



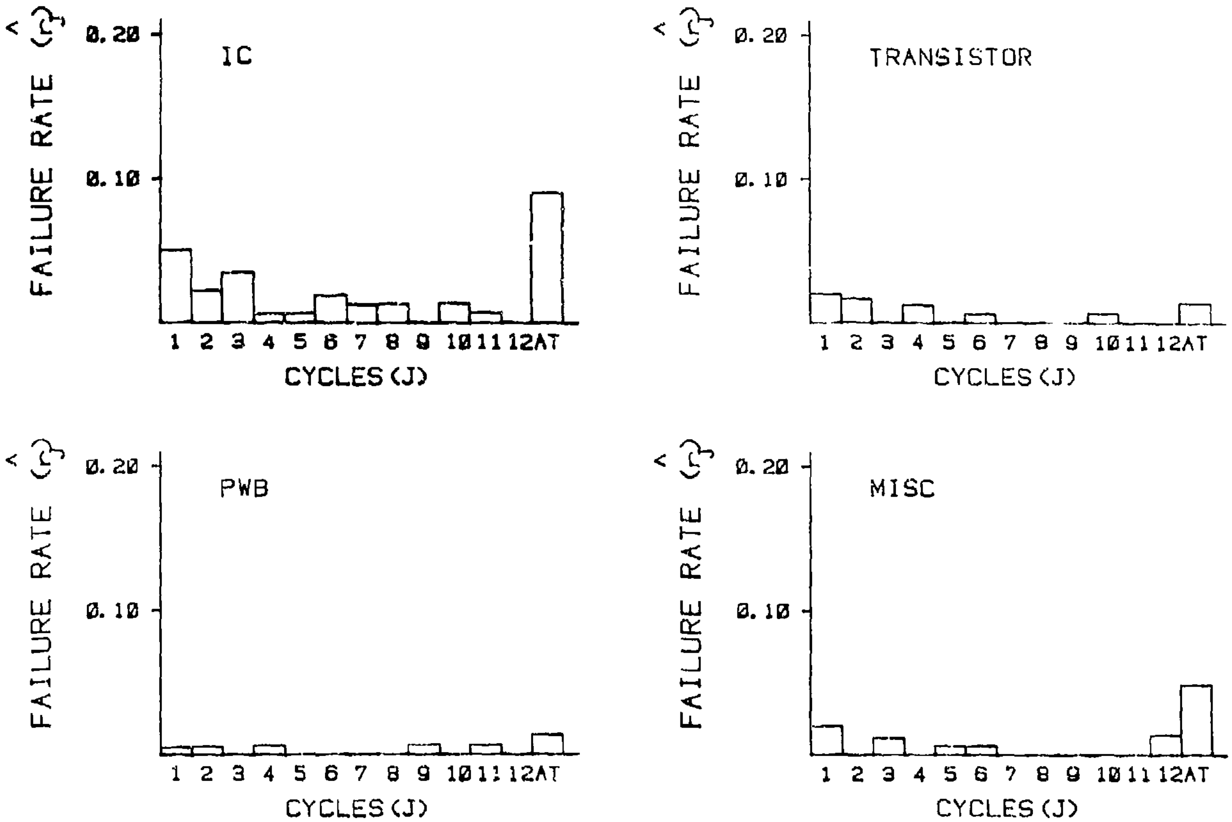
CYCLES (J)	1	2	3	4	5	6	7	8	9	10	11	12	AT
IC	15	8	7	4	3	4	3	4	2	6	3	3	7
CRT	2	2	2	0	1	1	1	0	0	2	0	0	1
SISTOR	2	1	1	0	0	0	1	2	0	0	0	0	0
PWB	5	0	1	1	1	0	0	0	0	0	1	0	1
MISC	4	0	1	0	0	1	1	0	1	1	0	0	1
UNITS (N J)	190	160	150	147	141	134	128	122	116	112	102	98	94

Figure 76. HUD DU Failure Rate by Part Class (12 Cycle Burn-In)



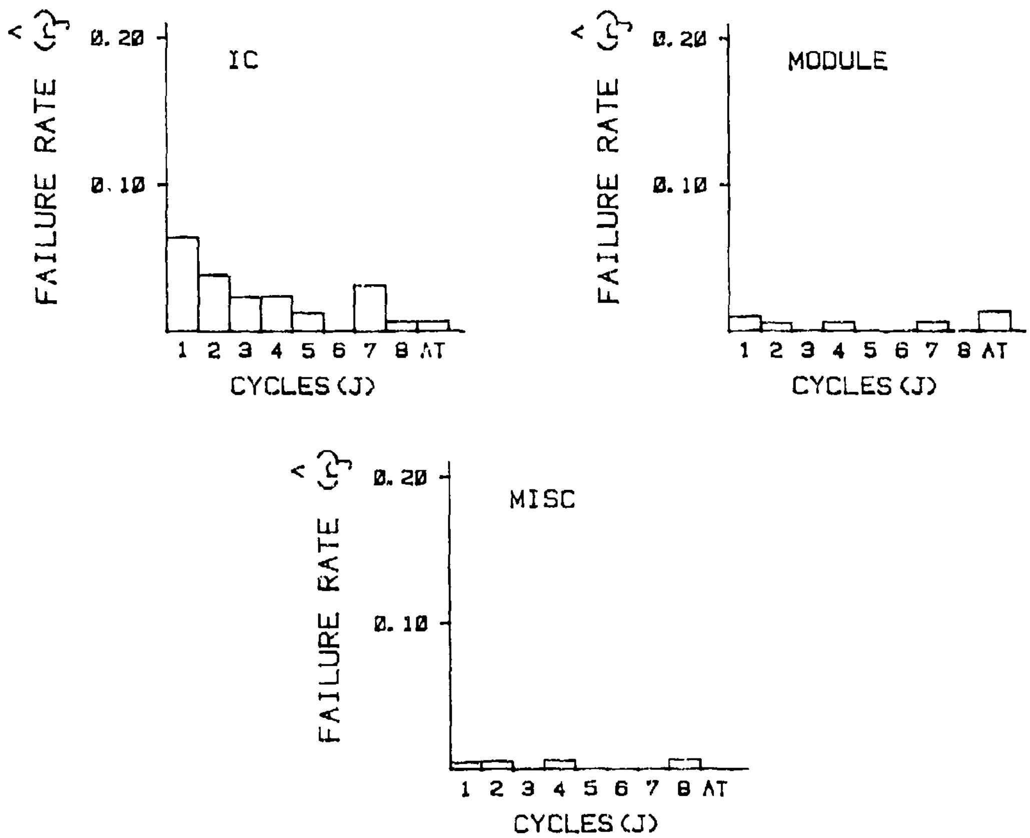
CYCLES (J)	1	2	3	4	5	6	7	8	AT
IC	4	Ø	1	Ø	Ø	1	1	Ø	1
CRT	2	Ø	1	Ø	Ø	Ø	Ø	Ø	3
MODULE	1	1	2	Ø	Ø	1	Ø	Ø	Ø
XSISTOR	1	2	Ø	Ø	Ø	Ø	Ø	Ø	1
MISC	2	Ø	Ø	Ø	1	Ø	Ø	Ø	5
UNITS (M_J)	2Ø3	188	186	18Ø	175	173	168	166	168

Figure 77. HUD DU Failure Rate by Part Class (8 Cycle Burn-In)



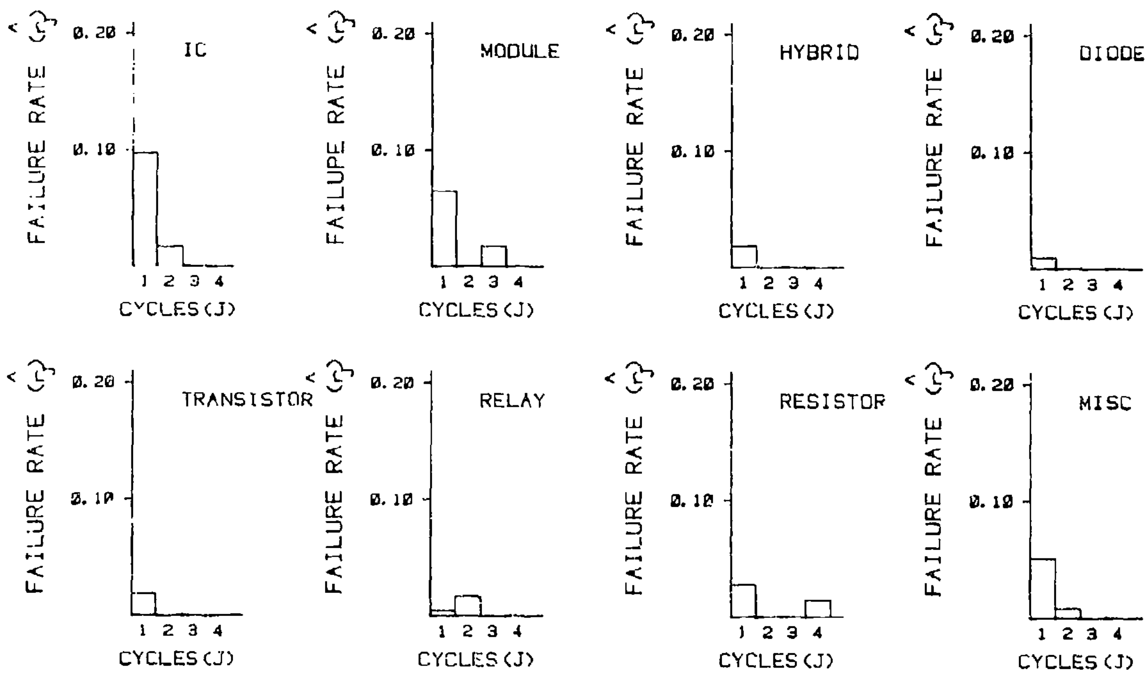
CYCLES (J)	1	2	3	4	5	6	7	8	9	1Ø	11	12	AT
IC	1Ø	4	6	1	1	3	2	2	Ø	2	1	Ø	13
XSISTOR	4	3	Ø	2	Ø	1	Ø	Ø	Ø	1	Ø	Ø	2
PWB	1	1	Ø	1	Ø	Ø	Ø	Ø	1	Ø	1	Ø	2
MISC	4	Ø	2	Ø	1	1	Ø	Ø	Ø	Ø	Ø	2	7
UNITS (Mj)	199	183	174	166	163	161	158	155	153	151	149	147	145

Figure 78. HUD SDP Failure Rate by Part Class (12 Cycle Burn-In)



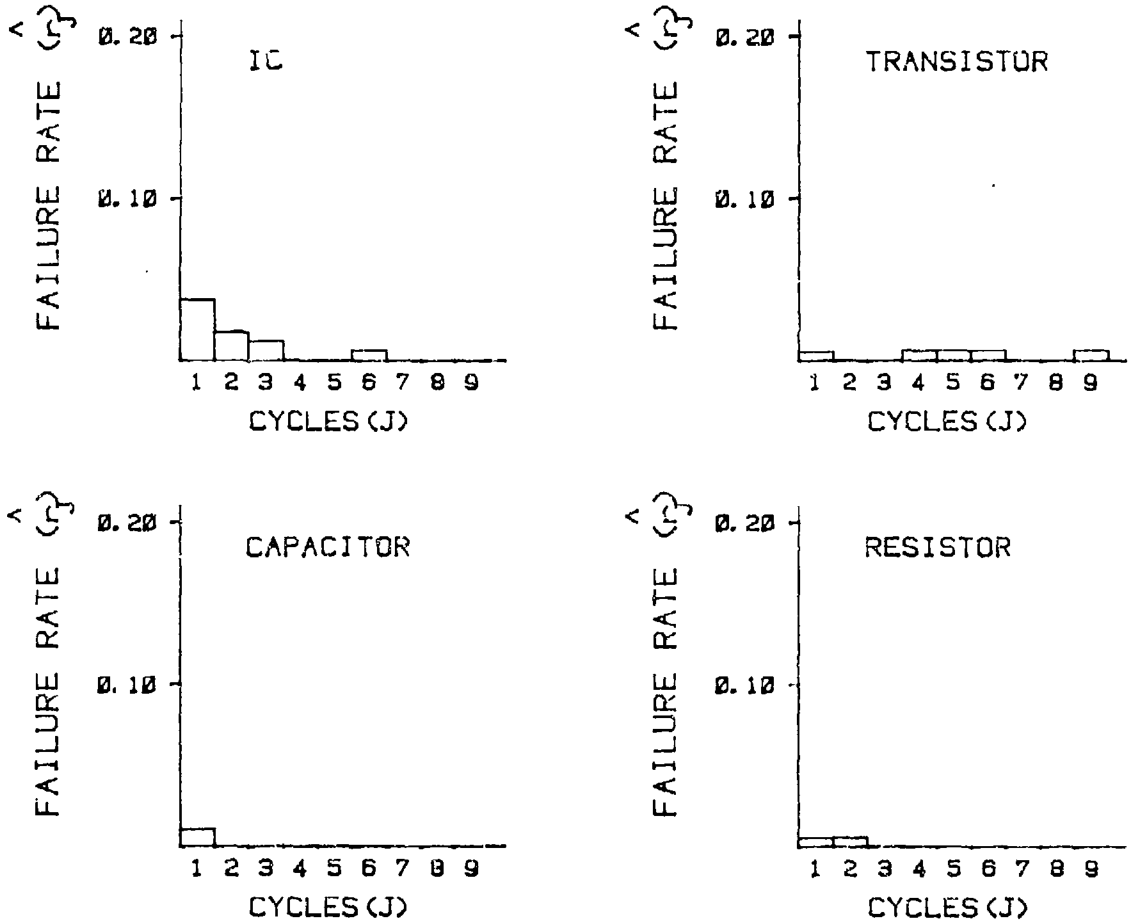
CYCLES (J)	1	2	3	4	5	6	7	8	AT
IC	13	7	4	4	2	0	5	1	1
MODULE	2	1	0	1	0	0	1	0	2
MISC	1	1	0	1	0	0	0	1	0
UNITS (M_J)	204	183	172	168	162	160	160	154	151

Figure 79. HUD SDP Failure Rate by Part Class (8 Cycle Burn-in)



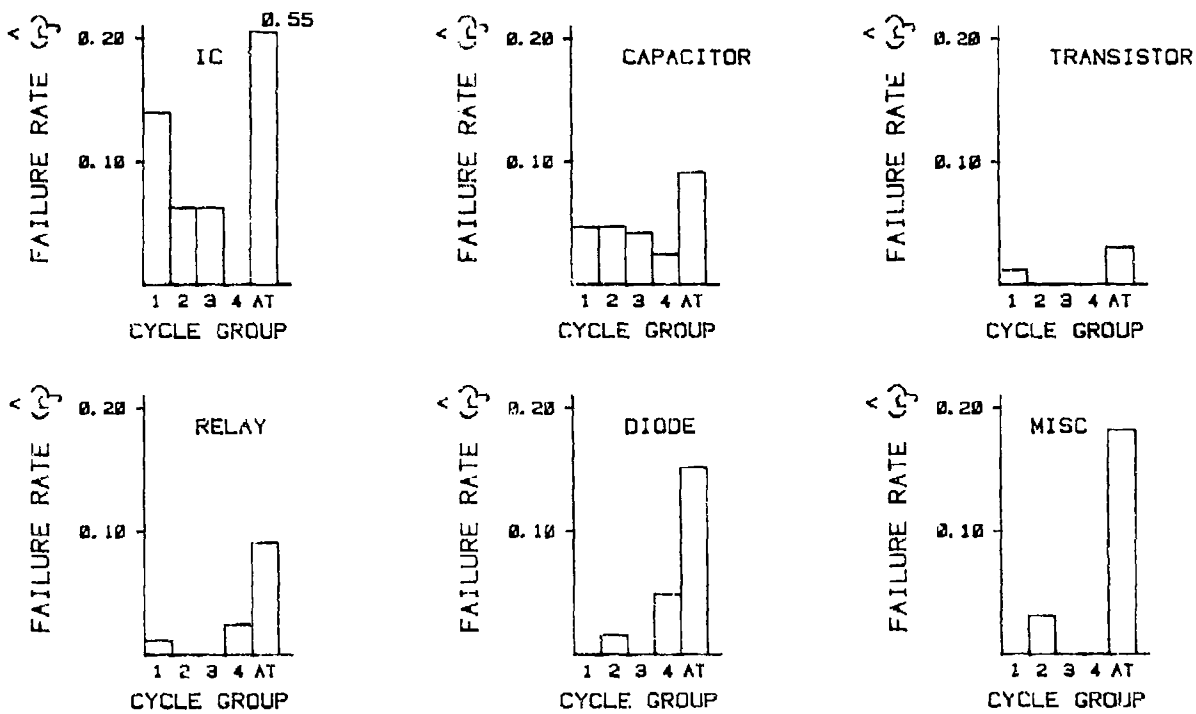
CYCLES (J)	1	2	3	4
IC	21	2	0	0
MODULE	14	0	2	0
HYBRID	4	0	0	0
DIODE	2	0	0	0
XSISTOR	4	0	0	0
RELAY	1	2	0	0
RESISTOR	6	0	0	1
MISC	11	1	0	0
UNITS (M J)	217	121	116	69

Figure 80. INS IMU Failure Rate by Part Class (3 Cycle Burn-In)



CYCLES (J)	1	2	3	4	5	6	7	8	9
IC	7	3	2	0	0	1	0	0	0
XSISTOR	1	0	0	1	1	1	0	0	1
CAPACITOR	2	0	0	0	0	0	0	0	0
RESISTOR	1	1	0	0	0	0	0	0	0
UNITS (M_J)	186	172	166	164	161	160	157	156	156

Figure 81. AFCS Roll/Yaw Computer Failure Rate by Part Class



CYCLE GRP	1	2	3	4	AT
IC	12	4	3	0	18
CAPACITOR	4	3	2	1	3
XSISTOR	1	0	0	0	1
RELAY	1	0	0	1	3
DIODE	0	1	0	2	5
MISC	0	2	0	0	6
UNITS	36	64	48	41	33

Figure 82. FGS Pitch Computer Failure Rate by Part Class

6. DISTRIBUTION OF DEFECT TYPE AND PART CLASS

The comparisons made in the last two sections were based on the failure rates for first failure. The distribution of defect types and part classes for first and second failure were also compared, to determine if the distribution changes after failure and repair of the unit.

In Tables 19, 20 and 21, the number of failures by defect type and failure number are presented for three equipments. These are the failures which occurred during the burn-in cycling and do not include acceptance test failures. In order to determine if the distribution changes after failure and repair, a Chi-Square test for independence was used. The Chi-Square values for tables 19, 20 and 21 are $\chi^2_{(2)} = 3.09$, $\chi^2_{(2)} = 2.14$, and $\chi^2_{(3)} = 3.94$ respectively. None of these are significant for $\alpha = .05$ indicating that the hypothesis of independence cannot be rejected. The implication is that the distribution of defect type is independent of the failure number.

A similar analysis can be used to determine if the part class distribution is dependent on failure number. The failures for three units by part class and failure number are shown in Figures 22, 23 and 24. The Chi-Square results are $\chi^2_{(4)} = 6.65$, $\chi^2_{(4)} = .791$ and $\chi^2_{(3)} = 6.72$ for the three tables in order of occurrence. All the tests are not significant for $\alpha = .05$.

7. INS RANDOM VIBRATION TEST

The INS production process contains a random vibration test, which is described in Section III. The results of this test on the sample of INS and NCI units are provided below.

A total of 224 INS units were subjected to the random vibration test, 26 of which failed. The probability of failure for the INS is estimated to be 26/224 = 0.116. Of the failures for which a defect type was identified, 42% were part defects, 21% were workmanship and 37% were CND. The number of failures for each defect type is shown in Table 25, along with the results of the three burn-in tests for first failure. A Chi-Square test for independence on the three burn-in tests yields $\chi^2_{(4)} = 1.075$, which is not significant for $\alpha = .05$. This indicates that the defect distribution is not significantly different from one burn-in test to another. If the defect distribution for the random vibration test is included, the result is $\chi^2_{(6)} = 15.7 > \chi^2_{(6)(.05)} = 12.6$. In other words the defect distribution for the random vibration test is significantly different than for the burn-in tests.

TABLE 19. HUD SDP FAILURES BY DEFECT TYPE AND FAILURE NUMBER (12 CYCLE BURN-IN)

Fail Number \ Defect Type	Part	Work	CND
1	49	0	5
2	17	1	3

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TABLE 20. HUD DU FAILURES BY DEFECT TYPE AND FAILURE NUMBER (12 CYCLE BURN-IN)

Fail Number \ Defect Type	Part	Work	CND
1	91	6	3
2	34	1	3

GP03-0630-16

TABLE 21. INS IMU FAILURES BY DEFECT TYPE AND FAILURE NUMBER (3 CYCLE BURN-IN)

Fail Number \ Defect Type	Part	Work	CND	UNK
1	69	7	9	12
2	30	0	4	8

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TABLE 22. HUD SDP FAILURES BY PART CLASS AND FAILURE NUMBER (12 CYCLE BURN-IN)

Fail Number \ Part Class	IC	TRAN	PWB	CAP	Diode
1	32	11	5	0	1
2	10	6	1	2	1

GP03-0630-18

TABLE 23. HUD DU FAILURES BY PART CLASS AND FAILURE NUMBER (12 CYCLE BURN-IN)

Fail Number \ Part Class	IC	Hybrid	CRT	PWB	TRAN
1	33	29	11	9	7
2	10	8	5	2	2

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TABLE 24. INS IMU FAILURES BY PART CLASS AND FAILURE NUMBER (3 CYCLE BURN-IN)

Fail Number \ Part Class	IC	Mod	Hybrid	Diode
1	23	16	4	2
2	8	9	2	6

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The random vibration testing of 182 NCI units yielded only three failures all of which were part defects. The probability of failure is estimated as 3/182 = 0.016. Table 26 shows the defect type distribution for first failure for the three burn-in tests and the random vibration test. The Chi-Square test yields $\chi^2(6) = 9.73$, indicating that the defect type distributions are not significantly different and we cannot reject independence. Due to the small number of random vibration failures, this is not unexpected.

TABLE 25. FAILURES BY DEFECT TYPE AND TEST FOR INS

Test \ Defect Type	Part	Work	CND
3 Cycle Burn-In (217 Units)	69	7	9
7 Cycle Burn-In (219 Units)	39	6	6
10 Cycle Burn-In (220 Units)	41	6	4
Random Vibration (224 Units)	8	4	7

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TABLE 26. FAILURES BY DEFECT TYPE AND TEST FOR NCI

Test \ Defect Type	Part	Work	CND
3 Cycle Burn-In	13	4	9
7 Cycle Burn-In	16	4	2
10 Cycle Burn-In	9	7	5
Random Vibration	3	0	0

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SECTION V

FLIGHT TEST RESULTS

The previous section has shown that the burn-in tests are effective in improving equipment reliability in the EBI environment, as evidenced by the decreasing failure rate during the tests. The decreasing behavior was found for all equipments, regardless of failure number (1, 2, ...).

The central question then became the behavior of the equipment failure rate during actual use conditions in the aircraft. If the flight failure rate is decreasing, this would imply that some tests exist (environmental or electrical) which could be performed prior to aircraft installation to improve the ensemble reliability of the equipment.

As shown in the following paragraphs a decreasing flight failure rate is characteristic of the military systems considered. Since these systems also achieved a constant failure rate in the EBI, the decreasing flight failure rate cannot be eliminated by increasing existing tests (more cycling). What is necessary is either the addition of other environmental screens (vibration, shock, etc.) or improved electrical performance tests during EBI and the acceptance test.

Most systems achieve a constant flight failure rate prior to delivery because of company flight tests. Thus the lack of a thorough burn-in does not significantly impact the user for equipment delivered in production aircraft. However, spares have no flight experience prior to user receipt.

Since the behavior of the flight failure rate is similar to the EBI failure rate, the model of Appendix A can be used to characterize the flight process. The model provides an estimate of the steady state failure rate, which is an estimate of the service failure rate or the reciprocal, the service mean flight hours between failure (MFHBF). As shown below the MFHBF estimates based on the production flight experience are consistent with actual field results.

1. <u>PRODUCTION FLIGHT TEST RESULTS</u> - At completion of the equipment production process units are transferred to the aircraft production facility for installation in production aircraft. The units are installed in the aircraft and a functional performance test is conducted prior to first flight. The units then experience about four flights prior to customer delivery. It is possible to use these flights to estimate the failure rate for the equipment. The failure rate is estimated similar to the burn-in failure rate except flights replace cycles in the presentation. As for burn-in, Equation A-14 of Appendix A is used to estimate the discrete failure rate.

Figures 83 and 84 show the flight failure rate for the military systems. Figure 83 contains the electronic equipments while Figure 84 includes primarily the AFCS sensors. Items listed as failures include all removals except those classified as CND, handling damage, or adjust only. The flight failure rate is decreasing in all cases except one, the SFS. The decreasing failure rate indicates that the unit population reliability is improving as additional flights are acquired and defective units removed. This situation is analogous to the decreasing failure rate observed in burn-in. It therefore is appropriate to use the model for decreasing failure rate developed in Appendix A. In order to estimate the model parameters, the average flight time for each flight (1, 2, . . .) must be known in addition to the information provided in the figures.

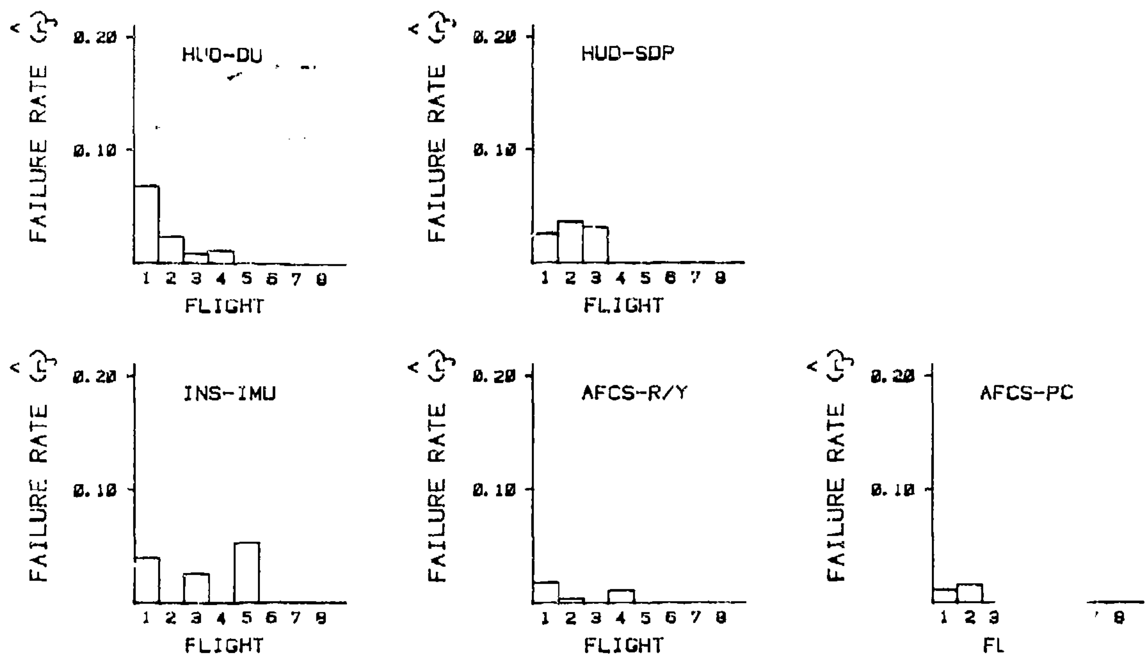
Table 27 indicates the average flight time for the various flights. Using the data from Figures 83 and 84 and Table 27 the maximum likelihood estimates for the model parameters were obtained by methods previously described.

Table 28 shows the resultant estimates for each equipment. In the table, the value $\hat{a}_0$ for several units is zero. This indicates that the lack of failures in the flights, of constant failure rate, precludes the estimation of $\hat{a}_0$. The estimate a_0 is an estimate of the constant failure rate which can be anticipated in service use. The reciprocal of $\hat{a}_0$ is $\hat{\mu}_0$, an estimate of the service mean flight hours between failure (MFHBF). An indication of the adequacy of $\hat{\mu}_0$ as an estimate of service MFHBF can be obtained by comparing the estimates to published service results.

Table 29 shows such a comparison using MFHBF estimates from Reference 5, commonly referred to as the 66-1 maintenance data collection system. The estimates ($\hat{\mu}_0$) for equipment with high MFHBF have a larger fractional error than those with low MFHBF. This is not unexpected since the flight time, in terms of MFHBF's, is less for the high reliability equipment.

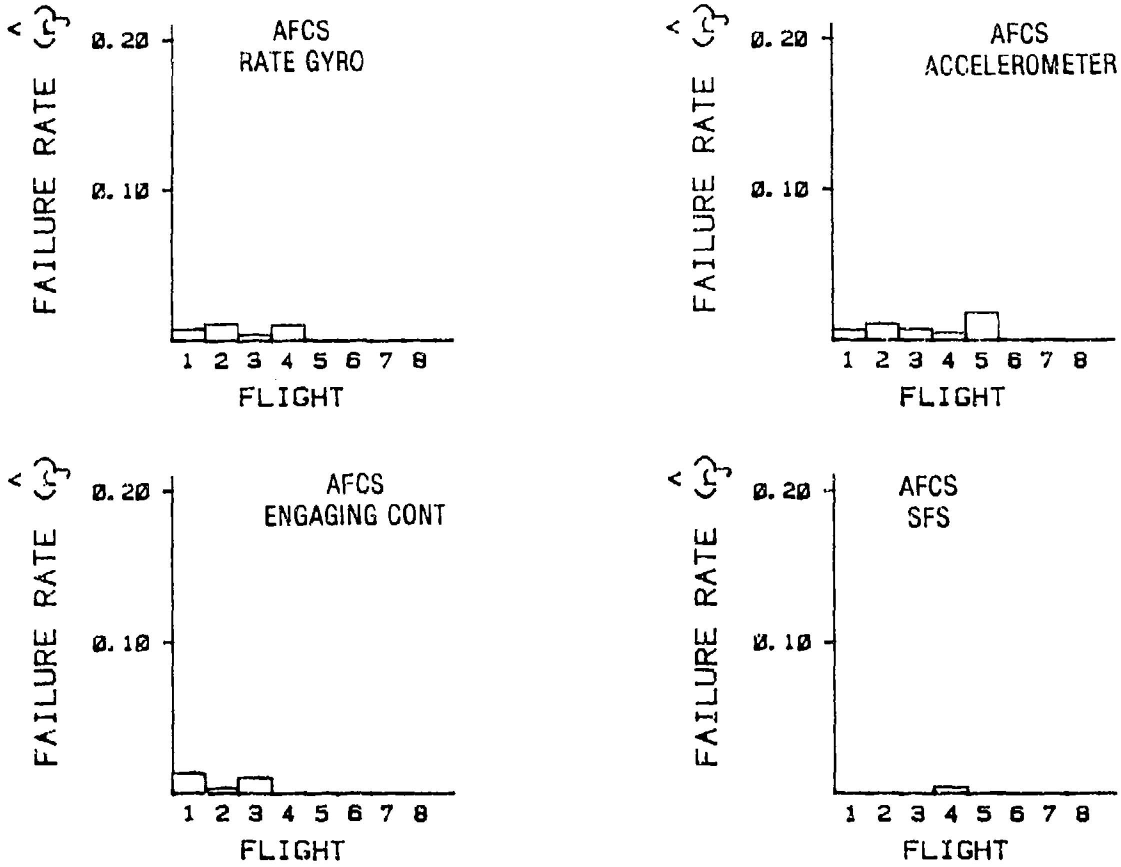
2. <u>FLIGHT TEST FRACTION DEFECTIVE</u> - As in the analysis of EBI results, the model parameters shown in the previous section can be used to estimate the fraction of units entering the production flight test which are defective, as defined in the model. This is referred to as the Flight Test Fraction Defective (FTFD) and is calculated using equation (A-9) from Appendix A and the value of a_1 from Table 28.

The results are shown in Table 30 for the military equipments. The value of zero for the AFCS SFS is the result of the model estimating a constant failure rate for the equipment ($\hat{a}_1 = 0$). The table indicates that the fraction of defective units entering production flight test is not insignificant. Four of the equipments have 5% or more. These defects represent escapes both from the equipment production facility and from the initial on-aircraft installation test.



	FLIGHT	1	2	3	4	5	6	7	8
HUD-DU	FAIL	10	3	1	1	0	0		
	UNITS	148	130	110	90	46	19		
HUD-SDP	FAIL	4	5	4	0	0	0		
	UNITS	156	138	127	93	52	19		
INS-IMU	FAIL	5	0	2	0	1	0	0	0
	UNITS	125	94	77	50	19	6	4	2
AFCS-R/Y	FAIL	5	1	0	2	0	0	0	0
	UNITS	275	254	238	177	90	35	11	3
AFCS-PITCH	FAIL	3	4	0	0	1	0	0	0
	UNITS	258	258	245	105	97	38	12	3

Figure 83. Flight Test Failure Rate for Electronic Systems



	FLIGHT	1	2	3	4	5	6	7	8
RATE GYRO	FAIL	2	3	1	2	Ø	Ø	Ø	Ø
	UNITS	281	275	258	199	1Ø1	41	11	2
ACCELEROMETER	FAIL	2	3	2	1	2	Ø	Ø	Ø
	UNITS	269	284	274	2Ø8	11Ø	43	14	3
ENGAGING CONT	FAIL	4	1	3	Ø	Ø	Ø	Ø	Ø
	UNITS	298	29Ø	285	217	11Ø	42	12	2
SFS	FAIL	Ø	Ø	Ø	1	Ø	Ø	Ø	Ø
	UNITS	3Ø7	3Ø1	295	228	12Ø	49	15	3

Figure 84. Flight Test Failure Rate for AFCS Equipments

TABLE 27. FLIGHT TIME vs FLIGHT NUMBER

Flight Number	Time (hr)
1	0.83
2	1.17
⩾ 3	1.33

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TABLE 28. MLE PARAMETER ESTIMATES FOR FLIGHT FAILURE RATE

Equipment	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$
HUD DU	0.0044	0.0850	1.6609
HUD SDP	0	0.1019	0.5013
INS IMU	0.0094	0.0482	40.3143
AFCS Roll/Yaw Computer	0.0027	0.0166	3.8895
AFCS Pitch Computer	0.0016	0.0229	1.0228
AFCS Rate Gyro	0	0.0398	0.2813
AFCS Accelerometer	0	0.1033	0.0837
AFCS Engaging Controller	0	0.0290	0.6306
AFCS SFS	0.0006	0	0.0003

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TABLE 29. MFHBF ESTIMATES AND SERVICE RESULTS

Equipment	$\hat{\mu}_o$	Service MFHBF
HUD DU	227	220
INS IMU	106	124
AFCS Roll/Yaw Computer	370	773
AFCS Pitch Computer	625	828
AFCS SFS	1606	2109

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TABLE 30. FLIGHT TEST FRACTION DEFECTIVE

Equipment	FTFD
HUD DU	0.0800
HUD SDP	0.1000
INS IMU	0.0500
AFCS Roll/Yaw Computer	0.0200
AFCS Pitch Computer	0.0200
AFCS Rate Gyro	0.0400
AFCS Accelerometer	0.1000
AFCS Engaging Controller	0.0020
AFCS SFS	0

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3. DELIVERED FRACTION DEFECTIVE - The DFD is an estimate of the fraction of units which are defective and delivered to the aircraft customer. This correspond to the screened fraction defective used for burn-in. Therefore, the DFD is calculated using Equation (A-8) of Appendix A. The DFD for the various systems is shown in Table 31 based on four flights prior to delivery.

4. TOTAL FRACTION DEFECTIVE - In Paragraph 2 above the fraction of defective units entering the production flight test was estimated. As mentioned earlier in this section, prior to the first flight, units receive a functional test and inspection when initially installed in the aircraft. Units which failed this initial test were not included in the sample used to estimate the flight failure rate for non-AFCS equipments. To obtain an estimate of the total fraction defective produced by the equipment supplier, the flight test fraction defective must be combined with the fraction defective found at initial installation. This total fraction defective (TFD) is an estimate of the probability that a unit received at the aircraft production facility is defective.

It is necessary to identify the two definitions of defective. In the flight test case we have the definition provided for by the model of Appendix A. In the case of initial installation, units are rejected or fail for numerous reasons. Some are rejected for what may be termed "nuisance" failures. These include such items as missing name plates, missing screws, bent connector pins, etc. In addition, units fail due to internal functional failure. These two classes of failure represent defective items in terms of receipt at the aircraft assembly point. Thus, all rejections or failures at initial installation can be considered as production defects.

There are essentially four causes for "failure". The first is that the unit is shipped from the supplier in a defective state due to errors in the production process. The second is failure in transit to the aircraft installation point. The third is that a different standard of performance may be imposed on the on-aircraft test as opposed to the supplier acceptance test requirements. This later cause exists because conditions during the unit test at the supplier are not identical to those required when the unit is installed in the aircraft. The fourth is the fact that the equipment has some non-zero failure rate during storage prior to aircraft installation.

The effect of these four sources is represented by the fraction of units rejected at installation in the aircraft. Let P_r represent this fraction or the probability the received unit is defective. This may be combined with defects from flight test (FTFD) to obtain the total fraction defective (TFD).

$$TFD = P_r + (1 - P_r)\ FTFD$$

TABLE 31. DELIVERED FRACTION DEFECTIVE

Equipment	DFD
HUD DU	0
HUD SDP	0.01
INS IMU	0
AFCS Roll/Yaw Computer	0
AFCS Pitch Computer	0
AFCS Rate Gyro	0.01
AFCS Accelerometer	0.07
AFCS Engaging Controller	0
AFCS SFS	0

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The TFD of the equipment for which estimates of P_r and FTFD were available are shown in Table 32. P_r represents all receiving rejections except those classified as CND, handling damage or adjust only. The difference between the TFD and the DFD represent the reliability improvement between the equipment supplier and delivery to the aircraft customer. As seen from the tables this improvement is not insignificant.

TABLE 32. TOTAL FRACTION DEFECTIVE

Equipment	P_r	FTFD	TFD	DFD
HUD DU	0.094	0.08	0.167	0
HUD SDP	0.074	0.10	0.166	0.01
IMU	0.119	0.05	0.163	0

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SECTION VI

COST EFFECTIVENESS CONSIDERATIONS

A decision rule has been developed to determine if a burn-in or other test/inspection technique is cost effective. It can be used to determine the maximum value of the burn-in based on repair costs, the produced fraction defective and the quantity of units considered. The cost effectiveness decision rule assumes that the produced fraction defective will remain the same regardless of whether or not burn-in is conducted. This is not necessarily the case. One of the intangible benefits of burn-in is the motivation it provides to produce defect-free equipment in order to reduce burn-in test cost. The produced fraction defective (PFD) estimated in previous sections was measured under the condition that a burn-in was required. If no burn-in were required it is not clear that other process controls would be sufficient to maintain the PFD at the same level as with burn-in. This aspect must be considered when evaluating the true benefit of the burn-in test.

1. DECISION RULE FOR COST EFFECTIVENESS - The decision rule for determining a policy for burn-in on a specific equipment is based on the minimization of the expected cost to the user. The expected cost if burn-in is not performed is compared to the expected cost if the burn-in is conducted. If the burn-in is not performed, then the expected cost is the repair cost for the defective equipments. The produced fraction defective (PFD) can be estimated from the burn-in model shown in Appendix A. Let M be the number of equipments for which the test is being considered and C_{FR} be the average cost to repair a unit by the user. Then the expected cost if no burn-in is performed (C_{NB}) is:

$$C_{NB} = M\ (PFD)\ \ C_{FR} \tag{1}$$

In defining C_{NB} above several implicit assumptions are made which indicate that C_{NB} is a liberal estimate of the no burn-in cost. Liberal implying that the value is biased on the high side of the true expected cost. First, the expression assumes all defects not detected by the burn-in will result in a service repair. This may be true for equipment procured directly by the user from an equipment supplier. However, as shown in Section V, a significant number of defects are removed in the aircraft production process. Thus M (PFD) is the largest number of defects expected to survive for user repair. The second assumption is that all defects precipitated by the burn-in process would be discovered as defects in service use. This may be true for a large percentage of the defects but is probably not true for all. For example, a transistor which fails only at temperatures below -40°C is unlikely to be considered a service defect. The likelihood of encountering such temperatures in actual operation is extremely remote. Thus, the expression for C_{NB} errs on the side of providing the maximum expected cost to the user if no burn-in test is performed.

If a burn-in test is conducted at a given cost C_T, the resultant fraction defective (P_B) will be less than the produced fraction defective PFD. The expected cost if a burn-in test is performed (C_B) is then:

$$C_B = C_T + M\ P_B\ C_{FR} \tag{2}$$

where again M is the number of units under consideration and C_{FR} is the cost of user repair. The above expression requires that the value of P_B associated with each test be known or estimated. The techniques of the previous sections provide such an estimate based on the number of burn-in cycles specified.

The decision rule for a specific test based on the minimization of expected cost may be defined as follows:

If $C_B < C_{NB}$, conduct burn-in

If $C_B > C_{NB}$, do not conduct burn-in

Using the expressions for C_B and C_{NB} obtained above, burn-in should be performed if:

$$C_T + M\ P_B\ C_{FR} < M\ (PFD)C_{FR}$$

or (3)

$$C_T < M(PFD - P_B)C_{FR}$$

This implies that if the test cost is less than the cost to repair the expected number of test-precipitated defects, the test is cost effective. It may be that there are several tests which satisfy (3). In this case, the optimal test (minimum expected cost) would be the test for which C_B is minimum.

Equation (3) may be used as a rough estimate of the value of the burn-in test to the user. For example, a typical one year production contract may specify 120 aircraft, 10 per month. Assuming one unit per aircraft implies M = 120.

Field repair cost will vary with the type of system, repair complexity etc. One recent estimate (Reference 6) indicates C_{FR} could be as much as \$15,000. In our example, assume C_{FR} = \$10,000. Also assume the burn-in reduces the fraction defective by 0.2 say from 0.20 to 0.00. Then from (3), the burn-in on the 120 units should cost less than

$$120(.2)(10K\$) = \$240K$$

Use of Equation (3) requires an estimate of both PFD and P_B. If the burn-in was perfect ($P_B = 0$) then the maximum value of the burn-in would be:

$$C_T^* < M\ C_{FR}\ (PFD) \tag{4}$$

where the * indicates the "perfect" test.

Use of Equation (4) requires an estimate of PFD, the produced fraction defective. If the equipment is in current production, PFD can be estimated from the test data by methods described previously. If no test data is available (program is in design or development) then estimates for PFD on similar systems should be used. If data from similar systems is unavailable, then the produced fraction defective can be estimated based on the unit part count using the relationship developed in Section IV as follows:

$$PFD = \begin{cases} 0.082\ N_p + .032 & \text{(Military)} \\ 0.117\ N_p + .114 & \text{(Commercial)} \end{cases} \tag{5}$$

where N_P is the unit part count in thousands.

Evaluation of the cost effectiveness of the burn-in tests for the six equipments studied was not possible. In many cases the EBI test was not priced as a separate contract line item and therefore included in the unit price. In others, while some data was available, the inconsistencies and variance in pricing practices from contractor to contractor made any evaluation meaningless.

SECTION VII

CONCLUSIONS

The conclusions presented below are primarily based on the analysis of the selected equipments. However, the specific equipments studied were selected as being representative of products and EBI tests in current use, to make the results as broadly applicable as possible to other avionics equipments.

1. The Environmental Burn-in improves the ensemble equipment reliability and no "wearout" degradation is apparent.

2. The number of cycles used for EBI on military systems can be reduced without changing the screened fraction defective.

3. Current EBI tests and production processes are not sufficiently thorough to <u>eliminate</u> infant mortality in the military aircraft use environment. On the other hand, aircraft production flight tests are generally sufficient to reduce the flight failure rate to a constant level prior to customer delivery. Additional EBI cycles alone will not reduce the initial flight failure rate.

4. The relatively high and decreasing failure rate for units after failure and repair (reburn-in) indicates that all tests should incorporate a number of consecutively failure-free cycles after failure in the EBI or post-EBI acceptance test.

5. The unreliability detected by EBI is primarily due to defective parts, as opposed to workmanship, process or design defects. More specifically, the EBI is primarily a screen for defective integrated circuits.

6. The ensemble reliability of units shipped directly from avionics suppliers to field use and not subjected to production flight test, is less than those delivered in production military aircraft.

7. As evidenced by the acceptance test failure rate, the performance tests used to assess whether a unit is failed during EBI are not as comprehensive and thorough as the acceptance test (AT). Environmentally sensitive failures, undetected in EBI, could also escape detection in the AT.

8. Failures which occur in the initial EBI cycles after start or repair are more likely to represent defects rather than chance failures.

9. The average number of defects per unit is proportional to part count.

10. There is no indication that the number of EBI cycles required to achieve a steady-state failure rate is proportional to the unit part count.

11. The Chance-Defective-Exponential (CDE) model is sufficiently flexible to characterize the diverse failure rates observed in the EBI tests.

12. The CDE model can be used to describe the equipment failure rate in flight use and provide an estimate of the service MFHBF based on production flight results for military aircraft.

13. MIL-STD-781B test levels E and F are the unofficial "Industry Standard" for EBI.

14. In general, EBI for commercial avionics is similar to that used for military equipment. However, the military test is usually more severe: hiqher and lower temperature limits, greater number of cycles, use of vibration, etc.

15. The design of EBI is primarily based on past experience. The customer's desires also play a major role.

SECTION VIII

RECOMMENDATIONS

1. Base the Design of Environmental Burn-In (EBI) tests on MIL-STD-781B test levels E and F.

2. Establish a test length sufficient to achieve a constant failure rate.

   Actual requirements will vary with supplier, type of equipment and production maturity and therefore should be established for individual equipments on a continuing basis. For new equipment designs, for which related experience is not applicable, a test length of 10 cycles is a recommended initial value. As EBI results are obtained, actual requirements should be based on analysis. In general, as a result of EBI failure analysis/corrective action and production maturity, the test length can be reduced. A test length of four cycles should be a minimum for most mature avionics products in the absence of any special aging considerations.

3. Incorporate a consecutive failure-free requirement encompassing EBI temperature cycles and the acceptance test.

   This requirement should be based on the minimum number of cycles necessary to reduce the failure rate of repaired units to a constant value. As with the test length, actual requirements will vary and should be established by analysis on a continuing basis. For new equipment designs, the failure-free period should include the last five EBI cycles and the subsequent acceptance test. Again as with the test length this should be adjusted based on test experience. For mature production, two cycles failure-free should be the minimum requirement.

4. Improve performance tests used to determine equipment failure during the temperature cycle.

   Current EBI tests are capable of precipitating environmentally sensitive failures without the auxillary capability for their detection. The level of performance test thoroughness which can be reasonably obtained may be limited by restrictions imposed by the environmental test facility. However, in many cases the level of thoroughness could approach that of the acceptance test.

5. Incorporate EBI requirements for spares.

   As evidenced in this report, spare LRU's are not as reliable as those delivered in production aircraft. Thus as a minimum, spare LRU's should receive the same burn-in as

production units. In some cases economics may indicate that more extensive testing of spare LRU's would be cost effective. A similar caveat applies to spares procurred at the SRA (card) level.

6. Initiate a comprehensive evaluation of the effectiveness of vibration and shock as an environmental screen for defective equipment.

The evaluation should address the adequacy and relative merits of mechanical shock and random, and sine-sweep vibration. This evaluation should also address the relative cost and effectiveness of combined environments (temperature and vibration) versus the use of both these environments separately. Such an evaluation would provide needed guidance and a firm technical foundation for the orderly, effective and economic evolution of the EBI test process.

APPENDIX A

MATHEMATICAL MODEL AND EFFECTIVENESS MEASURES

The purpose of environmental burn-in (EBI) is to improve equipment reliability by identifying defective components or manufacturing processes. Thus, any measure of EBI effectiveness must deal either directly with reliability improvement or with the defect identification capability of the EBI.

In order to provide measures on a stochastic process such as equipment reliability, it is useful to develop a statistical model. Once an adequate model has been developed, parameters can be estimated from test data and measures of EBI effectiveness obtained. The model used to represent equipment behavior is explained below.

1. CHARACTERIZING THE BURN-IN PROCESS - The burn-in process under consideration consists of repeated temperature cycles up to some limit, say K. If a unit passes all K cycles, it is removed from test. If a failure occurs in cycle j, $j = 1, 2, \ldots K$ the unit is repaired and returned for additional cycles depending on the burn-in test discipline.

This process is shown in Figure A-1. M is the total number of units tested and X represents the point of failure on the time line for a unit. t_1 is the time from the start of the test until the first failure occurs on a unit, t_2 represents the time from first failure to the second failure on a unit, and so on.

Let (t) equal the continuous variable, time.

Let $F(T) = Pr(t < T)$ = Cumulative Distribution Function (CDF)

$\bar{F}(T) = 1 - F(T) = Pr(t > T)$ = Survival Function (SF)

$f(t) = \frac{d}{dt} F(t)$ = probability density function (pdf)

and $\lambda(t) = \frac{f(t)}{\bar{F}(t)}$ = failure rate (fr)

In order to evaluate the burn-in process, we will want to assess the reliability of units as they proceed through it. We are interested in the reliability ($\bar{F}(t)$) of units prior to burn-in, during burn-in (how many cycles are required), and after burn-in. We proceed as follows:

Let the time between the i and (i-1) failure for the m^{th} unit $m = 1, 2, \ldots M$ be denoted $t_{i,m}$. We shall assume that $t_{i,m}$ is independent of m and identically distributed for all units. Dropping the m subscript, we denote the time between failure as t_i, $i = 1, 2, \ldots$ and denote the common SF as $\bar{F}_i(t)$ $i = 1, 2, \ldots$ Thus $\bar{F}_1(t)$ is the reliability of units entering the burn-in.

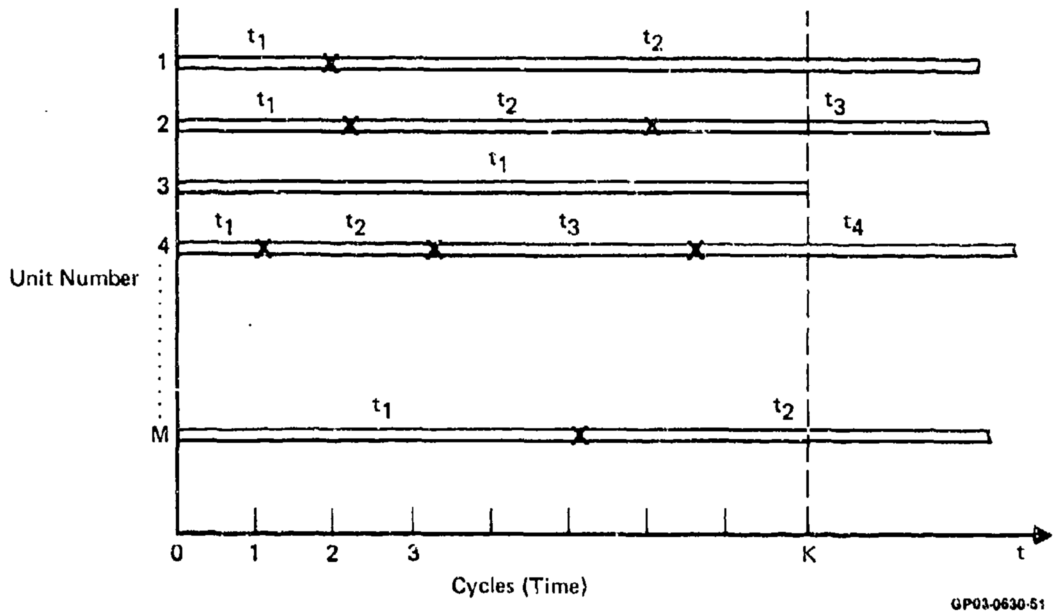


Figure A-1. Schematic Representation of Burn-In Process

$\bar{F}_1(t)/\bar{F}_1(T)$ is the reliability of units which survive a burn-in of length T without failure. $\bar{F}_2(t)$ is the reliability of units after one failure has occurred and $\bar{F}_2(t)/\bar{F}_2(T)$ is the reliability of units which have failed once and survived an additional time T prior to leaving burn-in. A similar relationship holds for units which have 3, 4, 5 failures, etc. In this fashion, the reliability behavior of the units in the burn-in process can be assessed.

2. THE CHANCE DEFECTIVE EXPONENTIAL

The family of distributions for $\bar{F}_i(t)$, i = 1, 2,... is specified by the Chance Defective Exponential (CDE). This family was proposed by Fertig (1976) and used to model burn-in results on electronic hardware in Fertig and Murthy (1978). The CDE family is based on the following three assumptions:

(1) The number of defective parts (n) in a unit is independent and identically distributed, and the distribution is binomial (N, p_D).

(2) The time between failure of a defect-free system is exponential (a_o).

(3) The time between failure of a defective part is exponential (a_2).

N is the total number of parts in the unit. The term part refers to identifiable physical subsets of the unit which can be removed. Thus, a part could be a resistor, IC, solder joint, connector pin etc. The unit or system is assumed to be serial in nature, so that the system fails if one of the parts fails. If the probability that a part is defective (p_D) is iid for all parts, then the number of defects (n) in a system of size N is a random variable, with binomial distribution and parameters (N, p_D) (Assumption 1).

Let the ensemble CDF for a defective part be denoted by $F_D(t)$ and the SF for the defect-free portion of the system of N-n parts be denoted by $\bar{F}_o(t)$ for all n, since N>>n. Then, the SF for the system (s) with n defective parts is:

$$\bar{F}_s(t|n) = \bar{F}_o(t)[\bar{F}_D(t)]^n \quad n = 0, 1, 2, \ldots, \; t > 0 \qquad \text{(A-1)}$$

Since for most systems of interest, N is large and p_D is small, the binomial distribution of n can be approximated by the Poisson with parameter $a_1 = Np_D$. The unconditional SF is:

$$\bar{F}_s(t) = \bar{F}_o(t) \sum_{k=0}^{\infty} \bar{F}_D^k(t) \frac{(a_1)^k}{k!} e^{-a_1} \quad a_1 > 0, \; t > 0 \qquad \text{(A-2)}$$

Performing the summation in (2) yields

$$\bar{F}_s(t) = \bar{F}_o(t)e^{-a_1(1 - \bar{F}_D(t))} \quad a_1 > 0, \; t > 0 \qquad \text{(A-3)}$$

From assumption (2) above, $\bar{F}_o(t) = e^{-a_o t}$ and from assumption (3) $\bar{F}_D(t) = e^{-a_2 t}$. Substituting these functions in Equation (3) yields the survival function:

$$\bar{F}_s(t) = \text{Exp}[-a_o t - a_1(1 - e^{-a_2 t})] \quad a_o, a_1, a_2 > 0, \; t > 0 \qquad \text{(A-4)}$$

Since the failure rate $\lambda_s(t) = \frac{-d}{dt} \ln \bar{F}_s(t)$

$$\lambda_s(t) = a_o + a_1 a_2 e^{-a_2 t} \qquad \text{(A-5)}$$

and the probability density function:

$$f_s(t) = \lambda_s(t)\bar{F}_s(t) = [a_o + a_1 a_2 e^{-a_2 t}]\exp[-a_o t - a_1(1 - e^{-a_2 t})]$$

(A-6)

Therefore the reliability of units during the burn-in process will be defined using the three-parameter distribution of (A-4). Since, for large t, $\lambda_s(t) = a_o$, a_o is referred to as the steady state failure rate and a_o^{-1} as the steady state MTBF. a_1 is the Poisson parameter for the number of defects in a unit, and is therefore referred to as the average or mean number of defects per unit.

3. EFFECTIVENESS MEASURES - Using the relationships developed in 2., various statements concerning the production population and the impact of the burn-in process can be formulated. The discussion which follows develops measures for units which enter the burn-in process and have time to first failure distribution $\bar{F}_1(t)$ with parameters a_o, a_1, and a_2. By analogy, these measures can also be used for units with 1, 2, 3 ... failures by substituting the appropriate parameters from $\bar{F}_i(t)$ i = 2, 3, 4 ...

a. Initial and Surviving Fraction Defective - One of the primary measures of EBI effectiveness is the probability that a unit which does not fail in a burn-in of length T is nevertheless defective (contains one or more defects) or, in symbols, $P(D|t > T)$. Equation (A-4) can be decomposed as follows:

$$\bar{F}_s(T) = \bar{F}_o(T)\bar{F}_D(T|D)P(D) + \bar{F}_o(T)P(\bar{D}) \qquad \text{(A-7)}$$

where: $\bar{F}_o(T)$ is the SF for the defect free portion of the system = $e^{-a_o T}$

$\bar{F}_D(T|D)$ is the SF for the defective portion of the system, given the system contains one or more defects

$P(D)$ = Probability the system is defective = $1-e^{-a_1}$

$P(\bar{D}) = 1 - P(D)$

The first term on the right hand side of (A-7) is the probability that a defective system survives a test of length T. The second term is the probability that a defect free system survives time T. So from (A-7)

$$P(D|t > T) = \frac{\bar{F}_O(T)\bar{F}_D(T|D)P(D)}{\bar{F}_S(T)}$$

$$= 1 - e^{-a_1 e^{-a_2 T}} \qquad a_1, a_2 > 0 \qquad T \geq 0 \qquad \text{(A-8)}$$

Solving (A-8) for T = 0, we have the probability that a unit is defective before the start of burn-in, or the Produced Fraction Defective (PFD)

$$\text{PFD} = 1 - e^{-a_1} \qquad a_1 > 0 \qquad \text{(A-9)}$$

The probability that a unit is defective given it has survived burn-in of length T is the surviving fraction defective (SFD), so from (A-8) we have:

$$\text{SFD}(T) = 1 - e^{-a_1 e^{-a_2 T}} \qquad a_1, a_2 > 0 \qquad T > 0$$

b. <u>Probability a Failure Is a Defect</u> - During the burn-in test when failures occur, the failed components may be subjected to a failure analysis of varying thoroughness, in hopes of determining the failure cause. If the cause is within the control of the production process, corrective action can be implemented. Since extensive failure analysis is expensive, it is of some interest to know the likelihood that a given failure is a defect whose removal improves the system reliability, as opposed to what is commonly referred to as a chance failure. Specifically, we would like to know the probability that a failure is a defect given that the system fails at some time T. In symbols, we wish to know $P(D|t = T)$.

Differentiating equation (A-7) we have:

$$f_S(t) = f_O(t)\bar{F}_D(t|D)P(D) + f_D(t|D)\bar{F}_O(t)P(D) + f_O(t)P(\bar{D})$$

from which we have:

$$P(D|t = T) = \frac{f_D(T|D)\bar{F}_o(T)P(D)}{f_s(T)} = \frac{g(T)}{\lambda_s(T)} \tag{A-10}$$

where: $g(t) = a_1 a_2 e^{-a_2 t}$

$$\lambda_s(t) = \lambda_o + g(t) = a_o + a_1 a_2 e^{-a_2 t} \qquad \text{from (A-5)}$$

c. Screen Improvement Factor - In order to provide an overall assessment of the adequacy of the EBI on the units, the decrease in SFD due to screening will be compared to the decrease which would be provided by a "Perfect Burn-in".

In a Perfect Burn-in SFD would be zero, so the change in SFD would be

$$\Delta SFD_p = PFD - SFD = (1 - e^{-a_1}) - 0 = 1 - e^{-a_1}$$

For the burn-in, the SFD is $= 1 - e^{-a_1 e^{-a_2 t}}$ from (A-8). The change in SFD for the burn-in is:

$$\Delta SFD_B = PFD - SFD = (1 - e^{-a_1}) - (1 - e^{-a_1 e^{-a_2 t}}) = e^{-a_1 e^{-a_2 t}} - e^{-a_1}$$

The Screen Improvement Factor (SIF) is the ratio of ΔSFD_B to ΔSFD_P or

$$SIF = \frac{e^{-a_1 e^{-a_2 t}} - e^{-a_1}}{1 - e^{-a_1}} \tag{A-11}$$

4. Estimation of Model Parameters - In order to provide the reliability estimates and measures of effectiveness mentioned in previous sections, the parameters of the CDF a_0, a_1, and a_2, must be estimated from the burn-in data for each time between failure. The following paragraphs develop the estimation technique for the parameters for time to first failure distribution. An analogous approach is used for the time between first and second, second and third failure, etc.

The burn-in process is shown schematically in Figure A-2, with only the times to first failure. Again, x represents the point of failure and K the total number of cycles in the burn-in.

In most EBI tests the exact time of failure is not known. What is usually reported is the cycle in which the failure occurred. Given a test of M units as shown in Figure A-2, the number of failures observed in each cycle is a random variable which depends on M and $\bar{F}_1(t)$. For a single unit, the probability of failing in cycle j given the unit has survived cycles 1, 2, ... (j-1) is r_j, the discrete failure rate.

If the SF of the unit is $\bar{F}_1(t)$ then:

$$r_j = \frac{\bar{F}_1(t_j) - \bar{F}_1(t_{j+1})}{\bar{F}_1(t_j)} \qquad j = 1, 2, \ldots, K \qquad \text{(A-12)}$$

where t_j is the time at the start of the j^{th} cycle. For the single unit, the number of failures in a cycle will be a Bernoulli random variable with parameter r_j.

Let x = 1 if a failure occurs and x = 0 if the unit survives. Then:

$$\Pr(x = 1) = r_j \qquad j = 1, 2, \ldots, K$$

$$\Pr(x = 0) = (1 - r_j)$$

The Bernoulli can be approximated by the Poisson for x = 0, 1 with parameter $\mu_j = \ln[\bar{F}(t_j)/\bar{F}(t_{j+1})]$. The approximation is valid if r_j is small.

If M_j is the number of units which survived cycles 1, 2, ..., (j-1) and attempted cycle j, then the total number of failures observed in cycle j (m_j) is:

$$m_j = \sum_{i=1}^{M_j} x_i$$

where x_i is the Bernoulli random variable (0, 1) for the i^{th} unit. If the Bernoulli is approximated by the Poisson with parameter μ_j then m_j has Poisson distribution with parameter $M_j\mu_j$. Using the definition of μ_j and SF (A-4) we have:

$$\mu_j = \int_{t_j}^{t_{j+1}} \lambda(u)du = a_0(t_{j+1} - t_j) + a_1(e^{-a_2 t_j} - e^{-a_2 t_{j+1}})$$

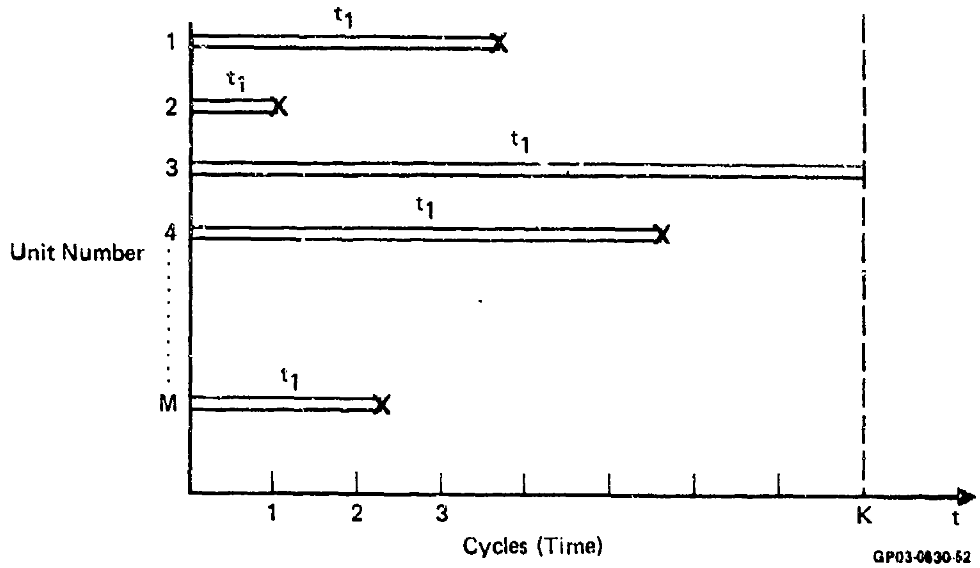


Figure A-2. Time to First Failure in Burn-In

Thus, for the EBI we observe m_j (the number of failures) from M_j (the number tested) over the interval (cycle) t_j, t_{j+1} for each cycle j = 1, 2, ...K. Since the number of failures in each cycle is Poisson and independent of other cycles, the likelihood function for the total EBI observation is:

$$\Phi(a_0,a_1,a_2 | m_j,M_j,t_j\forall_j) = \prod_{j=1}^{K} \frac{(M_j\mu_j)^{m_j}}{m_j!} e^{-M_j\mu_j} \qquad \text{(A-13)}$$

$$a_0,a_1,a_2 > 0$$

The maximum likelihood estimates (MLE) of a_0, a_1, a_2 are obtained by determining the values of a_0, a_1, a_2 which maximize (A-13), subject to the constraint that a_0, a_1, $a_2 > 0$.

In order to obtain the MLE, Equation (A-13) is solved using a MCAIR developed constrained optimization computer program. The program searches the admissible solution region (a_0, a_1, $a_2 > 0$) evaluating trial points and "climbs uphill" until the maximum value of the function (A-13) is obtained. The values of a_0, a_1, a_2 which provide this condition, are the MLE.

5. ESTIMATING DISCRETE AND AVERAGE FAILURE RATE - The discrete failure rate, r_j, defined in (A-12) above, is also estimated from the EBI test results. The estimate of r_j, denoted as $\hat{r}_j$, is:

$$\hat{r}_j = \frac{m_j}{M_j} \qquad j = 1, 2, \ldots K \tag{A-14}$$

where, as previously, m_j is the number of failures in cycle j and M_j the number of units which survived cycles 1, 2, ..., (j-1) and attempted cycle j. Since the number of failures in each cycle is distributed binomial with parameters (M_j, r_j) a confidence interval for r_j can be determined by solving:

$$\sum_{x = m_j}^{M_j} \binom{M_j}{x} [r_j(l)]^x [1 - r_j(l)]^{(M_j - x)} = \alpha$$

and

$$\sum_{x = 0}^{m_j} \binom{M_j}{x} [r_j(u)]^x [1 - r_j(u)]^{(M_j - x)} = \alpha$$

where $r_j(u)$ and $r_j(l)$ are the upper and lower $1-2\alpha$ confidence bounds.

The average failure rate over the interval t_j, t_{j+1} can be estimated by the MLE for the parameter of the exponential distribution in a test of fixed length. If the average failure rate is denoted by $\bar{\lambda}_j$ for cycle j, then

$$\hat{\lambda}_j = \frac{m_j}{M_j(t_{j+1} - t_j)}$$

Since in most EBI tests, the cycle length is the same for all j we have

$$\hat{\lambda}_j = \frac{m_j}{M_j \Delta t} \qquad j = 1, 2 \ldots K \tag{A-15}$$

and $\Delta T = t_{j+1} - t_j \quad \forall_j$

Since the sample is failure truncated, confidence bounds on $\bar{\lambda}_j$ can be obtained directly from the binomial confidence bounds $r_j^{(u)}$ and $r_j^{(l)}$ through the exponential distribution.

$$\bar{\lambda}_j^{(u)} = \frac{1}{\Delta t} \ln \left[\frac{1}{1 - r_j^{(u)}}\right]$$

$$\bar{\lambda}_j^{(l)} = \frac{1}{\Delta t} \ln \left[\frac{1}{1 - r_j^{(l)}}\right]$$

APPENDIX B

QUESTIONNAIRE FOR EVALUATING INDUSTRY PRACTICE IN THE ENVIRONMENTAL SCREENING OF AVIONICS

Return To: McDonnell Aircraft Co.
P.O. Box 516
St. Louis, MO 63166
Attn: J. R. Anderson
Dept. 346, Bldg. 32, L.2

GUIDELINES:

Please estimate (and so indicate) if data is unavailable.

Feel free to include existing charts, tables, etc. in order to facilitate your response to questions.

I. BACKGROUND

1. Company: ______________________________
(Do not abbreviate)

2. Name(s): ______________________________

3. Position: ______________________________

4. Telephone Number: (   ) ______________________________

5. Primary Avionics Products: ______________________________

____
(If Aircraft Prime Contractor List Aircraft)

6. Does your company use or specify the application of environmental stress (temperature, vibration, etc.) at the unit or LRU level on new production avionics in order to remove production defects from the equipment? This process is commonly referred to as environmental screening or burn-in.

a) ☐ Yes ☐ No

If no, do you use a power-on burn-in at room ambient conditions?

b) ☐ Yes ☐ No

If answer to 6b is yes, how long? ______________ hrs/unit

7. For each LRU you produce or specify please identify (in the table, page 2) the equipment type (computer, display, gyro, radar altmeter, etc.), whether the application is military (Mil) or commercial (Com) and identify the appropriate environmental screens (if used) for that LRU. If there are more than 7, include a cross section of equipment types and applications. See example.

SUMMARY OF ENVIRONMENTAL SCREEN PRACTICE

	LRU	1	2	3	4	5	6	7	Example
	AN Designator/ATA No.								AN/ASN-123
	Equipment Type								Inertial Platform
	Application								MIL
ENVIRONMENTAL SCREEN	Temperature Cycles								-60 to +160°F
	No. of Cycles								10
	Fail Free Cycles								Last 3
	High Temp. Only								
	Low Temp. Only								
	Sine Vibration								2.2g pk @ 20 HZ
	Sine Sweep Vibration								
	Random Vibration								
	Power-On Ambient								
	Other:								
	No Burn-In								

For the questions in Sections II and III refer to a particular avionics LRU and its associated environmental screen which is representative of your operation.

II. EQUIPMENT DATA

1. Military (AN) or ATA designator (optional) ______________

2. Type of equipment ______________
   (Digital Computer, Inertial Platform, etc.)

3. Aircraft which use this equipment ______________

4. Other types of equipment which use this screen ______________

   ____

5. Is the equipment for military or commercial use or both? ☐ Mil ☐ Com

6. Approx. parts composition (number by type and quality level)

		Quality Level*
______	IC's	______
______	Resistors	______
______	Capacitors	______
______	Transistors	______
______	Diodes	______
______	Misc.	*Per MIL-HDBK-217 if known
______	Total	

7. Power Consumption: ______ Watts

8. a) Production Rate: ______ per month b) Quantity Produced? ______

   c) How Long in Production? ______ years

9. Unit Price $______ (Rough order of magnitude)
   (Optional)

10. Are environmental screens used at the LRU level of assembly (i.e. board, module, piece part, etc.)

    ☐ Yes ☐ No ☐ Don't Know

    If Yes, describe screen used and assembly level

Screen	Assembly Level
______	______
______	______
______	______

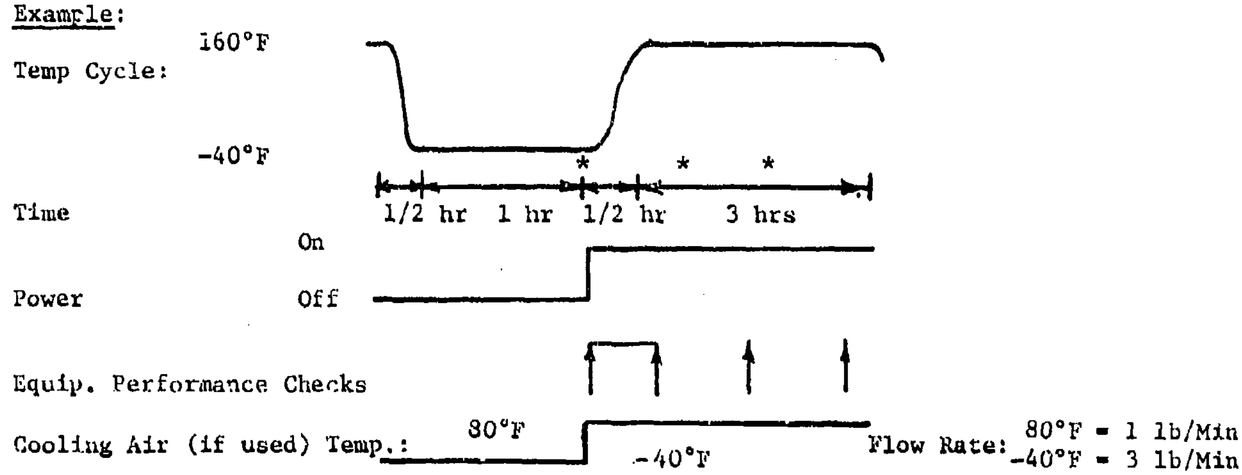
III. SCREEN DATA

1. Does the screen use a temperature cycle? ☐ Yes ☐ No

   If answer is yes; answer questions 2 thru 8.

2. Describe cycle with a diagram similar to the example. Please add any other information you feel is necessary to describe the test.

   Example:



   Temperature Rate of Change: 3°F/Min Cooling 4°F/Min Heating

   SCREEN DIAGRAM

   ___°F___

   Temp Cycle:

   ___°F___

   Time:

   Power: On / Off

   Equip Performance Checks:

   Cooling Air (if used) Temp: Flow Rate: ____________

   Temperature Rate of Change: __________ Cooling __________ Heating

3. Is vibration used in temperature cycle? ☐ Yes ☐ No
   If yes, answer question 4.

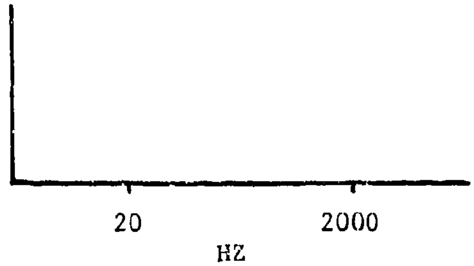
4. a) ☐ Sine ☐ Random ☐ Sine Sweep

☐ Other ______________________

b) Level ________ (g pk for sine, g rms for random)

c) Frequency (range) ________ Hz

d) For Random Sketch PSD ⟶ g^2/Hz



e) For Sine Sweep:

Sweep Rate = ________ Hz/Min

f) Duration of vibration

☐ Continuous ☐ Periodic for _____ min. each time

If periodic show with * when applied on the temperature cycle diagram above (see example).

5. Number of temperature cycles used ________

6. Failure Free Criteria: List the number of failure free cycles required and any special conditions.

________ Cycles ______________________________

7. If other equipments use this screen please answer the following for each equipment.

Application _____ (Mil/Comm) Equip Type ____________ (Analog Computer, CRT Display, etc) Cycles ______ (Number) Fail Free Cyc. ______ (Number)

Application _____ Equip Type ____________ Cycles ______ Fail Free Cyc. ______

Application _____ Equip Type ____________ Cycles ______ Fail Free Cyc. ______

Application _____ Equip Type ____________ Cycles ______ Fail Free Cyc. ______

8. Are other environmental screens used in addition to the temperature cycle?

☐ Yes ☐ No

If yes, briefly describe environment used, test characteristics and where in the screen sequence these test(s) are used, ie. before, after or between the temperature cycle test. If between, how many cycles before and after.

Environment: (If vibration is used describe using question 4 above.)

Test characteristics/Discipline (failure free req'ts):

Sequence location:

9. If temperature cycle is not used, please describe environmental screen used. If the screen uses vibration, answer question 4.

Environment:

Test characteristics:

Test discipline (failure free cycles, etc.):

10. What type of test is conducted immediately prior to the environmental screen?

____
(Integration Test, Functional Test, etc.)

11. What type of test is conducted immediately after the environmental screen?

____
(Acceptance Test, Functional Test, etc.)

12. Is performance of unit monitored during the environmental screen? ________
If Yes, please estimate the effectiveness of this test (in percent) relative to a full functional performance test and identify type of test.
___% Effectiveness

Type: ☐ Bit ☐ Functional Test ☐ Other ____________________
(Check One)

13. Do you have a failure rate plot versus cycle (time) for the environmental screen? ☐ Yes ☐ No

If yes, please include it as part of your questionnaire response.

14. Has the screen design (i.e. test environment, duration, levels, etc.) changed since initial production on this unit? ☐ Yes ☐ No

If Yes: a) What type of changes were made? (i.e., tests added/deleted, # of cycles, failure free criteria, etc.)

____

____

____

b) Why? ______________________________

____

____

15. The following are typical of the types of defects detected in the screening process. For each type please estimate a) their relative frequency of occurrence in percent, and b) the dominant cause of that failure type. For example: Part Defects 60%; Dominant Cause temperature sensitive IC's.

Defect Type	%	Dominant Cause
Part/Material Defects	____	______________________
Workmanship	____	______________________
Design Faults	____	______________________
Manufacturing Processes	____	______________________
Test Equip./Operator Error	____	______________________
Retest OK/Could-Not-Duplicate	____	______________________
Other	____	______________________
TOTAL	100%	

16. Average number of failures per unit in the screen? ______________

17. Screen Cost Data: ROM* Estimates (optional)

(a) Cost of test facilities necessary to perform this screen

$______________________________ (Est.)

(b) Average cost to screen a unit $______________ (Est.)

(c) Average cost to repair a unit $______________ (Est.)

(d) Average cost to repair a field return $______________ (Est.)

*ROM = Rough order of magnitude

18. Is the LRU tested as a system in the environmental screen or by itself?

____

IV. GENERAL

1. Please check any of the following environments which you or your organization have used as an environmental screen.

   - [ ] Temp. cycling with ________________ vibration.
     (Sine, Random, etc.)
   - [ ] Temp. cycling only
   - [ ] Sine sweep vibration
   - [ ] Random vibration
   - [ ] Shock
   - [ ] High humidity
   - [ ] High altitude
   - [ ] Other ________________

2. Of the items checked in question 1, identify ones which were found effective and on what types of equipment (i.e., digital computer, radar transmitter, etc.)

Environment	Equipment Types

3. Many temperature cycling screens consist of a soak at high temperature of 2 or more hours. It has been suggested that the soak is of little value and should be deleted in favor of additional cycling. Do you:

   - [ ] Agree   - [ ] Disagree   - [ ] No Opinion

4. The low level sine vibration used in many temperature cycling screens is of little value in detecting quality defects:

   - [ ] Agree   - [ ] Disagree   - [ ] No Opinion

5. Please rank the following vibration techniques in order of their general effectiveness in detecting production defects (if you feel some techniques are equal then assign them the same rank). 1 = HIGHEST

   _____ Sine   _____ Sine Sweep   _____ Random   _____ Other

6. Ranking in question 5 is based mainly on:

☐ Personal Experience ☐ Company Experience

☐ Literature (Papers, Reports, Symposia, etc.) ☐ Engineering Judgement

☐ Other ____________________

7. Do you feel that the effectiveness of environmental screens, in detecting production defects, would be improved if the screen environment was representative of actual service flight conditions (e.g. vibration levels and spectra, temperature profile, etc.)?

☐ Yes ☐ No ☐ No Opinion

8. Do you feel that a combined temperature and vibration screen is more effective in detecting production defects than the use of both these environments separately?

☐ Yes ☐ No ☐ No Opinion

9. Do you produce or specify both military and commercial avionics products of comparable function?

☐ Yes ☐ No

If Yes: a) Do the environmental screens used differ? ☐ Yes ☐ No

b) If Yes, describe how (in general)

____

____

____

c) What are the main reasons for the differences? (Check all that apply)

☐ Equipment Complexity

☐ Use Environment

☐ Differing Reliability Requirements

☐ Customer Requirements

☐ Other ____________________

10. The initial design of reen for a new production item is primarily based on: (choose all that apply)

- [ ] Previous experience on similar equipment
- [ ] Equipment characteristics (complexity, equip type, etc.)
- [ ] Customer's desires
- [ ] Test operating cost
- [ ] Use environment
- [ ] Existing environmental facilities
- [ ] Equip. reliability requirements
- [ ] Other ______________________________

11. How do the factors checked above in question 10 effect the screen design?

____

____

____

____

12. What information sources are used to evaluate the adequacy of environmental screens used in ongoing production?

- [ ] Customer experience data (MTBF, repair data)
- [ ] Screen results
- [ ] Results of tests prior to the screen
- [ ] Post screen production yield
- [ ] Cost/Failures
- [ ] Special reliability tests
- [ ] None
- [ ] Other ______________________________

13. How is this information evaluated to assess the adequacy of the screen?

____

____

____

14. In order to assess the effectiveness of various screening environments please rank (1 = HIGHEST) the screens listed for the following attributes:

Detectability: The ability to detect the wide range of types of production defects possible in produced hardware.

Efficiency: The rate at which defects are precipitated in hardware relative to other environmental screens.

False Alarm Potential: The relative number of failures and other test malfunctions which when corrected do not contribute to improved equipment (i.e. Retest-OK, failures atypical of service use, etc.).

Cost: Cost of test operation and facilities relative to other screens.

	Env. Screen	Detectability	Efficiency	False Alarm Potential	Cost
a)	Room Ambient: Power on for 48 hrs	______	______	______	___
b)	Temperature Cycling: 160°F to -65°F with 2 hr soak at 160°F. Six cycles. Last Cycle Failure Free.	______	______	______	___
c)	Sine Vibration: 2.2 g pk @ 20 $\leq$ f $\leq$ 60 Hz 30 minutes	______	______	______	___
d)	Random Vibration: @ 6 grms for 10 Min	______	______	______	___
e)	Shock:	______	______	______	___
f)	Humidity Test:	______	______	______	___
g)	High Altitude (70 KFT):	______	______	______	___
h)	Other: ____________	______	______	______	___

V. FINALE

1. Would you like to receive a summary copy of the report? ☐ Yes ☐ No

   If yes, give address ____________________

   ____

   ____

2. One last question: Please give your comments on where you feel the greatest potential lies for improving the effectiveness of environmental screening techniques and any other comments you have on the subject.

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Thank you for your participation. Your time and effort are greatly appreciated.

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